INTERCROPPING AND WHITEFLY (HOMOPTERA: ALEYRODIDAE) MANAGEMENT

By

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Field studies were carried out in north central Florida and central Guatemala to examine the effect of intercropping on numbers of whiteflies (Homoptera: Aleyrodidae). Squash (*Cucurbita pepo*) and eggplant (*Solanum melongena*) were tested as trap crops, and field corn (*Zea mays*) was tested as a barrier crop, for management of the silverleaf whitefly (*Bemisia argentifolii*) on common bean (*Phaseolus vulgaris*) in Florida between 1995 and 1997. Three distinct mixed and row-intercropping arrangements with poor and non-host crops were tested in 1998 in Guatemala to reduce densities of immature greenhouse whitefly (*Trialeurodes vaporariorum*) and sweetpotato whitefly (*Bemisia tabaci*) on common bean and tomato (*Lycopersicon esculentum*). In addition, a plastic mulch painted with a reflective aluminum strip was tested to reduce immature stages of

B. argentifolii alone and in combination with the squash trap crop in Florida, and two pesticides were tested as subplot treatments in two intercropping studies in Guatemala.

Counts from yellow sticky traps in the barrier test in Florida indicated that wind direction was the primary factor determining movement of adult *B. argentifolii*, and that the presence of a corn barrier only marginally affected the penetration of adults into test plots. None of the intercropping treatments consistently reduced densities of immature whiteflies compared to densities on crops grown in monoculture. Some intercropping treatments in the Guatemala studies reduced plant quality, making it difficult to interpret results. The reflective aluminum mulch treatment significantly reduced egg counts during the first week of sampling in two out of three years in Florida. Imidacloprid protected bean from damage by whiteflies and other sucking insects during the dry season in Guatemala, and reduced densities of immature whiteflies on tomato during the rainy season. A detergent and oil spray rotation did not protect bean from whitefly or other sucking insects during the dry season. Combining aluminum mulch or imidacloprid with intercropping treatments did not provide any additional advantage over using them alone. The lack of effect of intercropping on whitefly counts is discussed in relation to whitefly host-finding mechanisms and mobility. Methods for sampling immature stages of whiteflies on common bean are compared to determine the preferred sample unit and location within the plant canopy for sampling.

CHAPTER 1
LITERATURE REVIEW AND RESEARCH GOALS

Whiteflies

According to the system of classification commonly used in the United States, whiteflies (family Aleyrodidae) belong to the order Homoptera (Borror et al. 1989). As members of the suborder Sternorrhyncha, whiteflies are closely related to the psyllids, aphids, and scale insects (Campbell et al. 1996). They are considered by some to be the tropical equivalent of the aphids (Byrne and Bellows 1991). They occur throughout warm regions of the world, and under certain conditions, in temperate regions (Bink-Moenen and Mound 1990, Mound and Halsey 1978). The center of origin for aleyrodids is unknown, although Pakistan is considered likely because of the diversity of whitefly parasitoids in that region (Brown et al. 1995, Mound and Halsey 1978).

All known whiteflies are phloem-feeders (Byrne and Bellows 1991). Of the more than 1,200 species described (Bink-Moenen and Mound 1990), the majority are monophagous or oligophagous (Brown et al. 1995). However, polyphagy is common among economically important species, of which there are probably fewer than 20 (Byrne et al. 1990). Whiteflies cause crop losses by extracting water, amino acids and carbohydrates from the phloem, and by the production of honeydew, a sugar-rich excreta which accumulates on foliage and serves as a substrate for sooty molds (Hendrix et al. 1996). Sooty molds impede photosynthesis and reduce the quality of cotton (*Gossypium hirsutum* L.) lint and fruit (Byrne et al. 1990). In addition to causing mechanical damage,

at least three whitefly species cause widespread crop losses by vectoring plant viruses. *Bemisia tabaci* (Gennadius), the sweetpotato whitefly, vectors dozens of debilitating geminiviruses to a broad range of agronomic and horticultural crops (Brown 1994). *Bemisia tabaci*, *Trialeurodes vaporariorum* (Westwood), the greenhouse whitefly, and *Trialeurodes abutilonea* (Haldeman), the banded-wing whitefly, vector closteroviruses (Duffus 1996). Geminiviruses are transmitted in a persistent, circulative manner (Polston and Anderson 1997), and closteroviruses in a semi-persistent manner (Duffus 1996).

Bemisia tabaci and *T. vaporariorum* are the most economically damaging species of whitefly. Both species attack members of most major crop groups (Mound and Halsey 1978, Naresh and Nene 1980, Russell 1963, 1977). *Trialeurodes vaporariorum* has traditionally been a pest of greenhouse crops in Europe and the United States (Lloyd 1922, Vet et al. 1980), although in recent decades it has expanded its range, affecting glasshouse agriculture in Japan since 1974 (Yano 1983) and in Crete since 1979 (Roditakis 1990). It is a major pest of tomato (*Lycopersicon esculentum* Mill.) and cucumber (*Cucumis sativus* L.) grown in greenhouses, although successful biological control programs using parasitoids have been developed (Vet et al. 1980). In Central America, *T. vaporariorum* tends to be more common above 500 meters, and *B. tabaci* below 500 meters (Caballero 1994). *Trialeurodes vaporariorum* is a serious pest of tomato and other horticultural crops grown at higher elevations in Central America, while *Bemisia* and *Bemisia*-vectored geminiviruses are limiting factors at lower elevations (Hilje 1993).

Bemisia tabaci was first described in 1889 as a tobacco (*Nicotiana tobacum* L.) pest in Greece (Gennadius 1889). It was responsible for virus-induced crop losses during

the first decades of the century in Africa, Asia, India, and Latin America, primarily in cotton, tobacco, cassava (*Manihot esculenta* Krantz), and various legumes (Costa 1975). Large-scale monocultures of cotton in Central America and cotton and soybean (*Glycine max* L.) in Brazil favored massive increases in *B. tabaci* populations in those regions in the 1960s (Costa 1975, Dardón 1992). Until the early 1980s, *B. tabaci* outbreaks were largely sporadic (Bedford et al. 1994). By the end of the 1980s, a strain of *B. tabaci*, later described as a new species, had become one of the most important agricultural pests around the globe.

In Puerto Rico in the 1950s, researchers established that morphologically indistinct populations of *B. tabaci* existed with different host ranges. Strains or biotypes of *B. tabaci* based on host range were later recognized in Brazil and West Africa (Brown et al. 1995). In the mid-1980s, a strain of *B. tabaci* was introduced from the Mediterranean into the western hemisphere via the Caribbean, probably on ornamental plants (Brown et al. 1995, Polston and Anderson 1997). This strain was designated the B-biotype, or B strain, to distinguish it from the A-biotype, the prevalent North American strain (Costa and Brown 1990, 1991). The B-biotype appeared in Arizona, California, Texas, and Florida between 1988 and 1989, and within a few years had largely displaced the A-biotype throughout much of this region (Brown et al. 1995). By 1993, the B-biotype had been recorded throughout Central America and in Brazil (Brown et al. 1995).

The B-biotype has a broader host range than indigenous strains, causing serious infestations of poinsettia (*Euphorbia pulcherrima* (Willd.)), tomato, bell pepper (*Capsicum annuum* L.), broccoli (*Brassica oleracea* L.), cauliflower (*Brassica oleracea* L.), and alfalfa (*Medicago sativa* L.), none of which had been seriously affected by the A strain (Perring 1996). The new strain demonstrated greater rates of oviposition and

feeding on some crops (Bethke et al. 1991, Cohen et al. 1992). Byrne and Miller (1990) found that the B strain produced more honeydew than the A strain, and suggested that it might have better access to the phloem. Feeding by the B strain has been associated with the silvering of squash (*Cucurbita pepo* L.) and irregular ripening of tomato (Maynard and Cantliffe 1989), as well as other previously unknown plant disorders (Shapiro 1996). The B strain introduced dozens of new geminiviruses to the New World, primarily on the Solanaceae and Cruciferae. Many of these are still uncharacterized (Brown et al. 1995, Polston and Anderson 1997). Epidemics of bean golden mosaic geminivirus increased in Central America after the arrival of the B-biotype (Rodriguez 1994). In 1993, the first epidemic of bean golden mosaic was reported in south Florida (Blair et al. 1995). The B-biotype also exhibited high levels of resistance to carbamate, organophosphate, pyrethroid, and other pesticide groups compared to the A-biotype (Denholm et al. 1996, Dittrich et al. 1990).

Based on DNA differentiation tests, allozymic frequency analysis, crossing experiments, and mating behavior, Perring et al. (1993) reported that the B-biotype was a new species. Presenting differences in pupal case morphology and allozymic characters, Bellows et al. (1994) described the new species as *Bemisia argentifolii* Bellows & Perring, the silverleaf whitefly. The name was derived from the ability of the whitefly to induce silvering of leaves in certain cucurbits (Yokomi et al. 1990).

The elevation of the B-biotype to species has been disputed. Liu et al. (1993) reported that, based on esterase isozyme analysis, populations of the A- and B-biotypes mixed over time under laboratory conditions. Bartlett and Gawel (1993) argued that the molecular analysis carried out by Perring et al. (1993) was insufficient to demonstrate the existence of a new species. Brown et al. (1995) suggested that allozyme markers are

useful for tracking the spread of *B. tabaci* strains, but that they are not appropriate for the designation of species. They added that other distinct *B. tabaci* populations show significant variability in pupal case morphology, esterase banding profiles, and mating behavior. They reasoned therefore that if the B-biotype were a new species, other *B. tabaci* strains must be described as new species as well.

There seems to be consensus among many whitefly workers that the designation of *B. argentifolii* as a new species is "premature" (Bedford et al. 1994). The data suggest, however, that *B. tabaci* may be a species complex undergoing evolutionary change (Brown et al. 1995, Drost et al. 1998). Brown et al. (1995) believe that the A-biotype belongs to the New World group of *B. tabaci*, and that the B-biotype belongs to the Old World group. Brown et al. (1995) and Byrne et al. (1990) suggest that the B-biotype may have risen to predominance under the selective pressure of large-scale, heavily-sprayed monocultures, particularly cotton monocultures.

Crucial aspects of whitefly movement, host finding, and host acceptance have been described. Whiteflies are weak fliers and have been described as aerial "plankton," which move with the wind currents, probing plants as they are encountered (Byrne and Bellows 1991). Mound (1962) first reported that *B. tabaci* oriented toward either yellowish or blue/ultraviolet light, and suggested that this phenomenon might be related to colonizing and migratory behavior. Byrne et al. (1996) determined that *B. tabaci* has two distinct adult morphs, which engage in either trivial or long-distance movement. Trivial fliers orient toward the yellowish-green range of light spectra emitted by most vegetation, and seem to be predisposed to colonize. Long-distance fliers are attracted to ultraviolet light associated with the sky, and are apparently predisposed to migrate (Byrne

et al. 1996). *Trialeurodes vaporariorum* demonstrates similar orientation behavior to these two wavelength ranges (Coombe 1981, 1982, Vaishampayan et al. 1975a).

Neither *B. tabaci* nor *T. vaporariorum* respond to host-specific visual or olfactory cues (Mound 1962, van Lenteren and Noldus 1990, Vaishampayan et al. 1975a, 1975b). Feeding behavior studies and examinations of precibarial and cibarial chemosensilla of *B. tabaci* and *T. vaporariorum* indicate that the two species must probe a plant in order to determine if it is an acceptable host (Hunter et al. 1996, Lei et al. 1998, van Lenteren and Noldus 1990). Oviposition and longevity for each species vary on different crops. This has led to rankings of host suitability for *T. vaporariorum* (van Boxtel et al. 1978, van Lenteren and Noldus 1990, van de Meredonk and van Lenteren 1978), *B. tabaci* (Aslam and Gebara 1995, Costa et al. 1991, Coudriet et al. 1985, Naresh and Nene 1980, Simmons 1994), *B. argentifolii* (Chu et al. 1995, Tsai and Wang 1996, Wang and Tsai 1996), and to comparisons of host plant suitability for both species or biotypes of *Bemisia* (Blua et al. 1995, Drost et al. 1998). Survival and host plant selection by a whitefly female may be influenced by the plant species on which she was reared (Costa et al. 1991, van Boxtel et al. 1978). Both *B. tabaci* and *T. vaporariorum* emigrate from some host species more quickly than from others (Costa et al. 1991, van Lenteren and Noldus 1990, Verschoor-van der Poel and van Lenteren 1978). This may influence host-specific rates of oviposition.

Bemisia tabaci and *T. vaporariorum* females usually oviposit on the abaxial side of young leaves (Noldus et al. 1986a, Simmons 1994). *Bemisia tabaci* females seem to prefer a moderate degree of pubescence to either glabrous or extremely hairy leaf surfaces for oviposition (Butler et al. 1986, McAuslane 1996). First-instar nymphs tend to move a

short distance from the egg to find a feeding site, (Byrne and Bellows 1991, Price and Taborsky 1992), although they are capable of moving within and between plants to find healthy feeding sites (Summers et al. 1996). Subsequent instars are sessile. For this reason, nymph age tends to correlate with leaf age (Ekbom and Rumei 1990).

Researchers have taken advantage of this behavior to develop stratified sampling plans for "pupal" and parasitized stages of *T. vaporariorum* in greenhouses (Martin and Dale 1989, Martin et al. 1991, Noldus et al. 1986b) and egg and nymph stages of *Bemisia* on cantaloupe (*Cucumis melo* L.) (Gould and Naranjo 1999, Tonhasca et al. 1994a, 1994b), cotton (Naranjo and Flint 1994, Ohnesorge and Rapp 1986a, von Arx et al. 1984), peanut (*Arachis hypogea* L.) (Lynch and Simmons 1993, McAuslane et al. 1993), and tomato (Schuster 1998). *Bemisia* eggs and nymphs exhibit a highly aggregated distribution on leaves and across plants (Naranjo 1996). Sampling plans have been developed for whiteflies, primarily *B. tabaci*, to determine economic injury levels and to compare the efficacy of control measures (Butler et al. 1986, Ekbom and Rumei 1990, Naranjo 1996, Ohnesorge and Rapp 1986b).

Bemisia tabaci has demonstrated some degree of resistance to most classes of broad-spectrum pesticides (Denholm et al. 1996, Dittrich et al. 1990), although novel compounds (Horowitz and Ishaaya 1996) and "biorational" insecticides such as detergents and oils (Stansly et al. 1996, Veierov 1996) continue to provide some measure of control. One of the most effective and widely used compounds for whitefly control at the time of writing is imidacloprid, a systemic pesticide which inhibits nicotinergic acetylcholine receptors, produced by Bayer (Polston et al. 1994).

Host plant resistance to whiteflies is primarily derived from leaf characteristics such as pubescence or the presence of glandular trichomes (Berlinger 1986). Some degree of host plant resistance to *Bemisia* has been found in cotton (Flint and Parks 1990, Wilson et al. 1993), soybean (McAuslane 1996) and tomato (Heinz and Zalom 1995). Resistance to *T. vaporariorum* has been found in sweet pepper (*Capsicum annuum* L.) (Laska et al. 1986) and melon (*Cucumis melo* L. var. *agrestis*) (Soria et al. 1996). Progress has been achieved recently in developing resistance to *Bemisia*-transmitted geminiviruses in tomato (Scott et al. 1996, Nateshan et al. 1996).

The sessile habit of immature whiteflies renders them susceptible to many pathogens (Fransen 1990), predators, and parasitoids (Gerling 1990). Successful biological control programs have been developed to manage *T. vaporariorum* in greenhouses, primarily with the parasitoid *Encarsia formosa* (Gahan) (Hymenoptera: Aphelinidae) (Vet et al. 1980). In Florida, high rates of parasitism have been found on weeds, organically grown vegetables (Stansly et al. 1997) and unsprayed peanuts (McAuslane et al.1994). However, the intensive use of broad-spectrum pesticides and the rapid rate of increase of *Bemisia* prevents its suppression by natural enemies in most agricultural systems (Hoelmer 1996). Exotic parasitoids have been introduced into Arizona, California, Florida, and Texas to control *Bemisia* with little success (Hoelmer 1996, Nguyen 1996). Releases of predators in California (Brazzle et al. 1994, Legaspi et al. 1994, Roltsch and Pickett 1994) and attempts to establish refugia for natural enemies of *Bemisia* in the desert southwest have been similarly unfruitful (Roltsch and Pickett 1995, 1996). The arid conditions, heavy pesticide regimes, and continuous cropping cycles that characterize agriculture in the southwestern United States may place biological

control agents at a disadvantage (Hoelmer 1996). Crops tested as refugia include kenaf (*Hibiscus cannibinus* L.) and rosa de jamaica (*Hibiscus sabdariffa* L.) (Malvaceae) (Roltsch and Pickett 1995). Rosa de jamaica, also called roselle and sorrel in English, possesses extra-floral nectaries at the base of the leaf (Standley and Steyermark 1949).

Cultural methods used to reduce whitefly damage include manipulation of planting dates, use of short-season varieties, reflective mulches (Czizinsky et al. 1997, Powell and Stofella 1993), and floating row covers (Norman et al. 1993). Trap crops and intercropping have also been suggested as methods for management of *Bemisia* (Faust 1992).

Attempts to reduce whitefly damage with trap crops have produced unclear results. Squash (*Cucurbita pepo* L.) (Schuster et al. 1996), cantaloupe (*Cucumis melo* L.) (Ellsworth et al. 1994, Perring et al. 1995), soybean (McAuslane et al. 1995) and Wright's groundcherry (*Physalis wrightii* Gray) (Ellsworth et al. 1994) have been tested as trap crops for *Bemisia*. Whitefly densities on the main crop were either unaffected by the presence of the trap crop candidate, or were reduced on only a few sampling dates. Puri et al. (1996) intercropped cotton with wild brinjal (*Solanum khasianum* Clarke), which traps arthropods with a sticky exudate, without significantly reducing *Bemisia* densities in cotton. However, Al-Musa (1982) and Schuster et al. (1996) delayed the onset of virus in tomato by trap cropping with cucumber and squash, respectively. Al-Musa reported reductions of virus incidence of greater than 30% in tomato interplanted with cucumber.

Several tall-growing non-host plants, primarily in the family Gramineae, have been tested as barrier crops or intercrops to reduce whitefly colonization and virus

transmission among main crops. Results have been mixed. Morales et al. (1993) reported that a sorghum [*Sorghum bicolor* (L.) Moench] barrier slightly reduced *Bemisia* densities and transmission of virus on tomato in the Motagua Valley, Guatemala. A pearl millet [*Pennisetum typhoides* (Burm. f.) Stapf & Hubbard] barrier prevented whitefly virus transmission on cowpea [*Vigna unguiculata* (L.) Walp.] (Sharma and Varma 1984) and reduced it on soybean (Rataul et al. 1989) in India. In Colombia, Gold et al. (1990) found reduced densities of *Aleurotrachelis socialis* Bondar and *Trialeurodes variabilis* (Quaintance) on cassava intercropped with maize (*Zea mays* L.) and cowpea, but attributed this in part to reduced host quality due to intercrop competition. Ahohuendo and Sarkar (1995) reduced density of *B. tabaci* by more than 50% and incidence of cassava virus by 40% on cassava by intercropping with maize and cowpea in Benin. Fargette and Farquet (1988), whose study in the Ivory Coast included the effect of wind direction, found densities of *B. tabaci* and virus incidence were sometimes higher on cassava intercropped with maize than on monocropped cassava.

Successful management of *Bemisia* may require coordinated efforts throughout agricultural regions, such as the government-imposed host-free periods attempted in the Dominican Republic (Polston and Anderson 1997). Integrated pest management plans for tomato growers have been developed in Central America (Hilje 1993), and attempts to develop a collaborative model for whitefly management throughout the region are on-going (Hilje 1998). Ellsworth et al. (1996) describe efforts to develop a community-based *Bemisia* management program in Arizona. Kogan (1996) discusses the difficulties of adapting the integrated pest management for *Bemisia* to a region-wide management program.

Intercropping

Intercropping is the agronomic practice of growing two or more crops simultaneously in the same field (Andrews and Kassam 1976). Crops may be planted without regard to rows (mixed intercropping), in alternating rows, or with different crops alternating within the same row. Relay intercropping refers to planting of one intercrop species before another so that their life cycles partially overlap (Kass 1978). The broader term "polyculture" includes intercropping, but also encompasses intentionally combining crops and weeds, and combining crops with beneficial non-crop plants, such as cover crops or nursery crops (Andow 1991a). Perrin and Phillips (1978) include mixtures of crop cultivars and multilines in their definition of intercropping, because such combinations may possess some of the advantages associated with conventional intercropping.

Traditional food-production systems in tropical Africa, Asia, and Latin America are usually characterized by some degree of intercropping (Perrin and Phillips 1978). In agricultural areas where labor is the primary resource and reduction of risk the primary concern, polyculture systems have been developed which give higher and more secure yields than monoculture (Perrin 1977). Successful intercropping systems are characterized by greater efficiency in the use of solar radiation, nutrients, and soil moisture, as well as higher yields, compared to monocropped production under the same conditions (Andow 1991b, Kass 1978, Perrin 1977, Vandermeer 1989). In the first decades of this century, intercropping was common in temperate regions (Andow 1983). While generally considered inappropriate for the mechanized, chemical-intensive agriculture of industrialized nations, intercropping methods might improve the production

of high-value, labor-intensive fruits and vegetables in places like the United States (Capinera et al. 1985, Risch et al. 1983).

Among the agronomic benefits attributed to some systems of polyculture is the reduction of damage from arthropod pests (Altieri 1994, Altieri and Letourneau 1982, Andow 1983, 1991a, Kass 1978, Litsinger and Moody 1976, Perrin 1977, Perrin and Phillips 1978, Risch et al. 1983, Vandermeer 1989). This phenomenon was first discussed extensively in Western scientific literature in the earlier part of the twentieth century, based on observations of pest behavior in temperate and tropical silvicultural systems (reviewed by Andow 1983, and Pimentel 1961). Additional information came from traditional systems of polyculture in the tropics. Working in India, Aiyer (1949) proposed three ways intercropping might reduce pest damage: 1) individual plants might be more difficult to find because they are usually more dispersed in intercropped systems; 2) certain species might serve as trap crops, diverting pests from other crops; and 3) some crops might have a repellent effect on herbivores.

Elton (1927, 1958) suggested that the ability of natural enemies to suppress herbivores in naturally diverse agroecosystems was lost in simple systems, and promoted the idea that diverse systems should be more stable than simple ones. Diverse environments would offer a greater variety of habitats and victims to natural enemies (Huffaker 1958), as well as alternate food sources such as pollen and nectar (van Emden 1963, 1965), enabling natural enemies to suppress herbivore populations more efficiently than in simple environments. Drawing on Elton, Nicholson (1933), and his own work with pests of *Brassica oleracea* L. in simple and diverse systems, Pimentel (1961) refined this idea. He proposed that the varied but limited resources of diversified cropping

systems would support diverse but limited populations of both herbivores and natural enemies. Competition over resources would dampen oscillations among all trophic levels, creating a stable system, free from the pest outbreaks that characterized monocultures.

Root (1973) found that herbivores were less dense in *B. olereacea* grown in diverse than in simple stands, but determined that this could not be explained by increased activity of natural enemies. Summarizing the literature, Root explicitly defined the generally accepted "enemies" hypothesis, and added to it the "resource concentration" hypothesis to explain the reduction in herbivore load he had observed. According to the resource concentration hypothesis, herbivores with a narrow host range are more likely to find and remain on hosts grown in pure stands, and will attain higher relative densities in simple environments (Root 1973). Trenbath (1976, 1977) outlined the "fly-paper effect," a variation on the resource concentration hypothesis, which states that the time spent searching and probing diversionary intercrops will reduce the time and energy invested in damaging main crops, and may increase mortality among potential pests before they affect the main crop.

Vandermeer (1989) proposed three hypotheses to encompass all of the mechanisms suggested by Aiyer (1949), Root (1973), and Trenbath (1976, 1977). The "disruptive crop" hypothesis states that certain intercrop species will disrupt the ability of a pest to attack the main crop. The "trap crop" hypothesis refers to the ability of a more attractive intercrop to draw the pest away from the main crop. Intercrop systems which reduce herbivore densities by attracting more natural enemies than monocrops are examples of the "enemies" hypothesis.

The idea that diversity in itself reduces pest damage has been abandoned as inconsistent with empirical data (Andow 1991a). As Risch et al. (1983) point out, stability in pest populations is desirable only below economically damaging levels. However, reviews of the intercropping literature indicate that, relative to monoculture, herbivores were less dense in more than 50% of studies, more dense in 15 to 18 % of the cases, and variable in about 20 % (Andow 1991a, Risch et al. 1983). About 9% showed no difference in density between cropping systems. Recent analysis has focused on rigorous examination of the two hypotheses defined by Root (1973) in an attempt to determine under which conditions polyculture might be useful for pest management (Andow 1991a, Corbett and Plant 1993, Kareiva 1983, Power 1990, Risch et al. 1983, Russell 1989, Sheehan 1986, Stanton 1983). The trap cropping mechanism has been ignored by all reviewers except Vandermeer (1989).

Neither the resource concentration hypothesis nor the enemies hypothesis has proven to be consistently useful for predicting how crop density and diversity will affect arthropod density or diversity (Kareiva 1983, Russell 1989). Andow (1991a) and Risch et al. (1983) state that, based on reviews of the literature, the resource concentration hypothesis tends to account for herbivore response to polyculture more often than the enemies hypothesis. However, given the high degree of variability in response by some herbivores, Andow (1991a) suggests that this generalization is of limited predictive value. Russell (1989) writes that studies which have compared insect abundance in simple and diverse systems have uncovered little evidence to support the enemies hypothesis.

The inability to explain arthropod response to vegetative diversity with a few broad mechanisms has been attributed in part to the many adaptive variations that

characterize arthropod behavior. Kareiva (1983) states the need for research that identifies "species specific traits...that govern the responses of herbivores to vegetation texture." The ability of an herbivore to colonize a given cropping system, diverse or simple, will depend largely on the range of its diet, the nature and sophistication of its host-finding mechanisms, and its relative mobility (Kareiva 1983, Stanton 1983). The same holds true for plant disease vectors (Power 1990) and natural enemies (Russell 1989, Sheehan 1986). The specific nature of vegetative diversity will also determine arthropod response. Vegetative texture can vary in terms of density, patch size, spatial array, and temporal overlap (Andow 1991a, Kareiva 1983), as well as the ratio of host to non-host plants, which will have a greater influence on herbivore abundance than the actual number of plant species (Power 1990, Stanton 1983).

Vegetative diversity can affect arthropod damage and densities by influencing the rate at which an arthropod immigrates into a cropped area, its population dynamics once it has entered, and the rate at which it emigrates from the area (Stanton 1983). The extent to which immigration can be influenced depends on the host-finding mechanisms and mobility of the arthropod. Intercropping with certain crops may interfere with the olfactory cues certain insects rely on for host-finding (Perrin 1977, Stanton 1983). For instance, Tahvanainen and Root (1972) demonstrated that tomato volatiles interfered with host-finding by *Phyllotreta cruciferae* Goeze, a flea beetle, and led to reduced oviposition on collards. Interference with visual host-finding cues has been suggested (Perrin 1977, Stanton 1983). However, most examples of manipulation of visual perception concern increased attraction of insects such as aphids to sparsely planted crops which stand out against bare ground (Kennedy et al.1961, Smith 1976).

The extent to which vegetative diversity will interfere with immigration also depends on the range at which an insect detects the host, and whether this detection mechanism is specific or general (Kareiva 1983, Stanton 1983). Host-specific orientation cues tend to be characteristic of monophagous insects (Prokopy and Owen 1978), which may in addition evolve sophisticated searching ability in order to find rare hosts. Polyphagous insects such as certain whiteflies and aphids do not rely on host-specific visual or olfactory cues, and respond generally to the spectra of yellowish light emitted by most vegetation (van Lenteren and Noldus 1990, Power 1990). Whiteflies, aphids, and thrips have limited ability to control their flight, and have been described as "aerial plankton" (Byrne and Bellows 1991, Price 1976). The "flypaper effect" (Trenbath 1976) suggests a mechanism by which weak fliers with unsophisticated host-finding mechanisms such as whiteflies and aphids might be reduced in polyculture. Simply by alighting on and probing diversionary intercrops, such insects may invest less time in damaging main crops. However, this mechanism has not been demonstrated scientifically.

Trap cropping is a method of pest suppression that relies on manipulating host-finding mechanisms. The herbivore's decision-making must be influenced before it finds and damages the main crop. Vandermeer (1989) writes that trap cropping should affect generalist herbivores. However, the sensitive host-finding cues of monophagous herbivores are presumably more vulnerable to manipulation than the general attraction to most vegetation demonstrated by some polyphagous insects. Hunter and Whitfield (1996) almost doubled yields and reduced densities of the Colorado potato beetle (*Leptinotarsa decemlineata* (Say)) by more than half by using potato as a trap crop with

tomato. Trap cropping has been used to manage the cotton boll weevil (*Anthomonus grandis* Boheman) in Nicaragua (Swezey and Daxl 1988) and Arizona (Moore and Watson 1990). The ability to support higher densities than a main crop does not make a "preferred" crop a trap crop; the trap crop must actually reduce densities on the main crop when the two are interplanted (Ali and Karim 1989). Trap crops are often treated with pesticides to prevent damaging herbivores from building up and spilling over onto main crops (Srinivasan and Moorthy 1991). Effective control often depends on the timing of pesticide applications to the trap crop (Todd and Schumann 1988) or the timing of planting for the trap crop in relation to the main crop (Kloen and Altieri 1990).

There are several ways herbivore density, damage, and growth may be affected by vegetative diversity once an insect has entered a polyculture. Polycultures which support high densities of natural enemies may increase predation and parasitism of herbivores (Altieri and Letourneau 1982). For example, Letourneau (1987) found parasitism of *Diaphania hyalinata* L. higher in squash intercropped with corn and bean (*Phaseolus vulgaris* L.) than in monocropped squash. Intercropping may affect herbivore health by affecting the suitability of individual plants, or by repelling certain insects because of increased shading (Kareiva 1983). Hawkes and Coaker (1976) reported that *Delia brassicae* (Wied.), the cabbage root fly, oviposited less on *Brassica* sp. intercropped with clover (*Trifolium* sp.) than in pure stands. This was apparently due to higher rates of departure from hosts within the patch rather than to increased difficulty finding them (Coaker 1980).

The effect of polyculture on the transmission of arthropod-vectored pathogens may vary according to the epidemiology of the pathogen. Incidence of non-persistent

viruses has been reduced on main crops by diverting aphid vectors to "protection crops" (Jenkinson 1955, Broadbent 1969). Crop combinations which cause vectors to probe more frequently but for shorter periods of time may increase the incidence of non-persistent viruses, and reduce the incidence of persistent viruses (Power 1990).

Rates of arthropod emigration from a vegetatively diverse patch may be influenced by searching behavior. Insects which restrict their search area upon finding a host ("patch restricted searching") may be more likely to remain within a diverse area than insects whose movement is unaffected by encountering a host ("uniform searching") (Stanton 1983). Highly mobile insects may leave a diverse area after encountering a number of non-hosts in succession. Bach (1980a, 1980b) and Risch (1980, 1981) found that leaf beetles emigrated more quickly from patches of hosts mixed with non-hosts than from pure stands, and were able to show that increased emigration was responsible for lower beetle densities in polyculture compared to monoculture. Being weak fliers, aphids, whiteflies, and thrips (the "aerial plankton" group) may simply move short distances from plant to plant until they find acceptable hosts. This passive method of searching may cause such insects to accumulate in higher densities on hosts in polyculture, if these hosts are planted at a lower density than in monoculture.
Root's (1973) hypothesis that crop diversity would tend to reduce densities of monophagous herbivores rather than polyphagous ones is supported by the preceding summary, and by reviews of the intercropping literature (Andow 1991a, Risch et al. 1983). Andow (1991a) found that 28% of polyphagous herbivores studied had lower densities in polyculture, while 40% had higher densities. Only 8% of monophagous herbivores had higher densities in polyculture, while 59% had lower densities.

The success and efficiency of natural enemies in polyculture relative to monoculture is largely determined by the specifics of behavior, much as it is for herbivores. The enemies hypothesis implicitly refers to generalist natural enemies, in that it suggests polyculture will offer alternate prey or hosts, and alternate food sources, such as pollen and nectar (Root 1973). Like specialist herbivores, specialist natural enemies such as host-specific parasitoids may rely on sensitive visual, olfactory, and tactile cues to find hosts. These cues are more likely to be obscured in polyculture than in monoculture (Sheehan 1986). The disruption of plant patches may cause a specialist enemy to leave a diverse area more quickly than a simple one. Host-feeding is essential for some parasitoids, and alternate protein and carbohydrate sources such as nectar or pollen may not serve as a substitute (Sheehan 1986).

There are many examples of predators achieving higher densities in monoculture than polyculture (Corbett and Plant 1993). For instance, Schultz (1988) found significantly fewer lacewing (Chrysopidae) eggs on cotton intercropped with corn or weeds than on monocropped cotton. The assumption that predators will move from a resource-rich intercrop to the main crop that the agriculturalist intends to protect may not always be valid. Bugg et al. (1987) found that predators on knotweed (*Polygnum aviculare*) did not tend to move from it to adjacent crops.

Few robust generalizations can be made to predict how polyculture will affect arthropod density (Andow 1991a, Kareiva 1983). However, the literature suggests that polyculture will reduce densities of monophagous herbivores more often than densities of polyphagous herbivores (Andow 1991a). In addition, polyculture may favor some

generalist predators, but is more likely to impede the efficiency of specialist parasitoids (Pimentel 1961, Sheehan 1986).

Inadequate research methods have contributed to the ambiguity surrounding the effect of polyculture on arthropods. Intercropping often reduces plant quality relative to monoculture (Andow 1991a, Kareiva 1983). Some authors include the effect of reduced plant quality in their analysis (for instance Gold et al. 1990, Schultz 1988), but many do not (Kareiva 1983). Stanton (1983) remarks that there may be significant differences in how researchers and insects perceive "diversity." In addition, Andow (1991a) writes that results of polyculture studies have varied depending on whether polyculture treatments were substitutive or additive, i.e. whether host plant density was different in monocrop and intercrop treatments.

The greatest difficulty in designing field tests of intercropping effects on arthropods is determining the appropriate scale of plots and distance between plots (Russell 1989, Stanton 1983). Some arthropods may perceive a patchwork of monocropped and intercropped plots as one large polyculture. Small clustered plots will increase the influence of patch borders on searching, and the likelihood that arthropod density in one treatment plot is influenced by the arthropod's attraction to or rejection of a distinct adjacent treatment plot (Andow 1991a, Stanton 1983). Plot size will affect the ability of herbivores and natural enemies to find hosts, as well as their foraging behavior within the plot, and the rate at which they leave it (Corbett and Plant 1993, Kareiva 1983, Stanton 1983, Russell 1989).

Research Objectives

The objective of the following research was to determine if intercropping could be used to reduce densities of immature whiteflies compared to densities on crops grown in monoculture. Intercropping studies were designed to test the reduction of whitefly densities on bean and tomato. It was hoped that results from these crops would apply to other economically-important crops. Population densities, and in some cases yield, were measured to estimate whitefly incidence and damage under simple and mixed systems, although damage was not measured directly.

Summarizing the literature, Vandermeer (1989) proposed three all-encompassing hypotheses to explain how intercropping might reduce pest damage (trap crops, disruptive crops, and increased natural enemies). The following field experiments focused on testing two of these hypotheses, the trap crop hypothesis and the disruptive crop hypothesis. The first set of experiments, carried out on an organic farm near Gainesville, examined squash as a trap crop. The second set of experiments, carried out on a University of Florida agricultural research farm near Gainesville, tested eggplant as a trap crop and field corn as a barrier crop. The final set of experiments tested the potentially disruptive effect of intercropping bean or tomato with poor or non-hosts of whitefly. These last studies took place at a government agricultural research station in central Guatemala. Data were gathered on parasitism in most of these studies, and on predators in a few studies, but only the final experiment in Guatemala attempted to test the third intercropping hypothesis, the enemies hypothesis, by intercropping with cilantro to augment densities of generalist predators.

An additional objective of the research was to determine if whitefly suppression through intercropping could be enhanced by integration with other control strategies. In the first set of studies, plastic mulch with a strip of reflective aluminum paint was tested alone and in combination with the trap crop. Imidacloprid and a detergent/oil rotation were tested as subplot pesticide treatments in some intercropping studies in Guatemala. The final study in Guatemala included an initial evaluation of methods for protecting tomato seedlings from whitefly damage in the nursery stage.

CHAPTER 2
THE EFFECT OF SILVER REFLECTIVE MULCH AND A SUMMER SQUASH (*CUCURBITA PEPO* L.) TRAP CROP ON DENSITIES OF IMMATURE *BEMISIA ARGENTIFOLII* (HOMOPTERA: ALEYRODIDAE) ON ORGANIC BEAN (*PHASEOLUS VULGARIS* L.)

Introduction

Bemisia argentifolii Bellows & Perring, the silverleaf whitefly (also known as *Bemisia tabaci* (Gennadius) strain B), has become a serious pest of horticultural and agronomic crops throughout warm regions of the world (Brown et al. 1995). Since the mid 1980s, the Florida vegetable industry has lost millions of dollars due to a variety of diseases and disorders associated with *B. argentifolii* (Norman et al. 1993). These include the tomato mottle and bean golden mosaic geminiviruses (Hiebert et al. 1996), as well as irregular ripening of tomato and squash silverleaf (Maynard and Cantliffe 1989). *Bemisia* has developed resistance to most classes of pesticides (Denholm et al. 1996, Dittrich et al. 1990), forcing conventional growers to seek non-chemical alternatives to *Bemisia* management. Synthetic pesticides are not an option for organic growers, who face special challenges in the management of virus vectors.

The present study was undertaken to assess the efficacy of reflective plastic mulch and yellow summer squash (*Cucurbita pepo* L.) as a trap crop for management of *B. argentifolii* on snap bean (*Phaseolus vulgaris* L.) on an organic farm in north central Florida. Florida is the foremost producer of snap bean in the United States (National Agricultural Statistics Service 1998). In 1995, revenue from fresh market snap bean in Florida exceeded $50 million (Florida Statistical Abstract 1996). Plastic mulches which

reflect ultra-violet rays are disorienting to certain insects (Prokopy and Owens 1983) and have been used to repel virus vectors such as aphids (Smith and Webb 1969, Jones 1991) and thrips (Smith et al. 1972, Scott et al. 1990). Schuster and Kring (1988) reported some success using reflective mulch to manage whiteflies.

Trap crops are preferred host plants which are used to draw herbivores away from a less-preferred main crop (Vandermeer 1989). Trap crops are sometimes sprayed with pesticides to prevent the damaging herbivores from building up and spreading to the main crop (Ellsworth et al. 1994). Several crops have been tested as trap crops for management of *Bemisia* (Al-Musa 1982, Ellsworth et al. 1994, McAuslane et al. 1995, Schuster et al. 1996). By the early 1990s, squash had been singled out as a promising trap crop candidate for management of *Bemisia* (Faust 1992).

Material and Methods

The study was carried out on a 4-ha certified organic farm, 6 km northwest of Gainesville, Florida (29° 40'N, 82° 30'W). Four treatments were compared: 1) bean grown on bare soil ("bean"), 2) bean grown with reflective polyethylene mulch ("mulch"), 3) bean mixed with squash grown on bare soil ("squash") and 4) bean mixed with squash grown with reflective mulch ("squash/mulch").

'Espada' garden bean seed and 'Multipik' yellow summer squash seed from Harris Seed (60 Saginaw Drive, Rochester, New York) were used. Seed had been previously treated with captan (N-(trichloromethyl)thio-4-cyclohexene-1,2-dicarboxamide), metalaxyl (N-(2,6-dimethylphenyl)-N-(methoxyacetyl)alanine methyl esther), streptomycin and chloroneb. It is acceptable for organic growers to use treated seeds if untreated seeds are unavailable (Organic Materials Review Institute 1998). To ensure uniformity among covered and exposed beds, all beds were formed using a Rainflo

plastic mulch layer (model no. 560, Rainflo Irrigation, East Earl, PA). Plastic mulch and drip irrigation tubing were laid over all beds, which were 1.22 m wide. After planting, plastic mulch was removed from the bare soil treatments.

Beans were planted 15 cm apart within the row. Squash replaced every fifth bean plant in the squash treatments. Beds were 3.5 m long, and the space between beds was 2 m. Each treatment plot contained two beds with two rows of plants per bed. The reflective mulch was a white polyethylene mulch with a central stripe of silver pigment, 61 cm wide (product 60-64S/W125PR, North American Film Corporation, 19 Depot Road, Bridgeport PA).

There was concern that whiteflies might colonize certain borders of the experimental area before others because of wind direction or migration from adjacent host plants. To control for two potential extraneous sources of variation, treatments were arranged in a 4 x 4 latin square design.

Plots were irrigated as needed using drip irrigation. Plants were fertilized 3 weeks after emergence and at flowering with approximately 250 g per row of 3-2-3 (N-P_2O_5-K_2O) North Florida Brand composted chicken manure. Plots were hand-weeded as needed. No pest control products were applied to the experimental area.

The study was repeated in 1995, 1996 and 1997. In 1995, crops were planted on October 15. The following years, crops were planted on September 2.

Sampling

Sampling for whiteflies began one week after crop emergence. Sampling was stopped after 4 weeks in 1995 because of a freeze. Bean and squash were sampled for 6 weeks in 1996 and 1997. Four or 5 plants were sampled per plot each week. The sample unit was a 3.34 cm^2 leaf disc cut from upper and lower leaves using a number 13 nickel

cork borer (McAuslane et al 1995). Discs were taken from the underside of the leaf, in the lower half of the leaf to the right of the mid-vein. Samples were examined using a dissecting stereoscope set at 20x and numbers of whitefly eggs, nymphs, parasitized nymphs, and red-eyed nymphs were recorded.

Yield

Pods were harvested week and fresh weight was recorded for weeks 7, 8, and 9 after planting.

Virus Screening

After harvest, leaf tissue from 6 plants from each plot was collected and tested with a dot blot hybridization technique for the presence of geminivirus (Rojas et al. 1993). Analysis was conducted by the laboratory of Dr. E. Hiebert at the Department of Plant Pathology at the University of Florida. Bean tissue (50 mg) was extracted in 200 mM NaOH with 1% SDS. Geminivirus DNA-A component was amplified by PCR with Maxwell degenerate primers (PAL1v1978 and PAR1c496). The amplified DNA was used for a 32P random-primed labeling reaction (Life Technologies RTS RadPrime DNA Labeling Systems). The membrane was hybridized with 32P labeled probe in 6x SSC, 5x Denhardts solution and 0.5% SDS at 65° C for 16 hrs. The membrane was then washed under high stringency conditions with 0.2x SSC and 0.1x SDS at 65° C. Finally the membrane was exposed to X-ray film for 16 hrs.

Statistical Analysis

Whitefly counts were transformed by $\log_{10}(x+1)$ because of low counts during the first year and unequal variance over time. Treatment comparisons were made of upper leaf counts, lower leaf counts, and of the average of the two strata. Treatments were compared with time as a variable, and then by individual week, using analysis of variance

(PROC MIXED, SAS version 6.11, SAS Institute 1996). When appropriate, treatment means were compared using Tukey's Studentized Range test with an adjusted experiment-wise error rate of α =0.05. Yield data were analyzed using the same analysis of variance and mean separation procedures. Counts in upper and lower strata within the same treatment were compared using a pairwise t-test. Bean samples which tested positive for the presence of bean golden mosaic virus were assigned a value of 1, and negative responses were assigned a value of 0. Responses were then analyzed using logistic regression.

Results

Research Design

A latin square design was used because of the concern that some blocks might become colonized by whiteflies before others due to their proximity to infested hosts or their orientation to prevailing winds. It was observed during this and concurrent studies that populations of whitefly adults require minutes rather than days or weeks to move from one end of an experimental area to the other. It was decided therefore that the latin square design was unnecessarily complicated for studying whiteflies, and that a randomized complete block design would be adequate for future studies. However, the data was analyzed using analysis of variance for latin square. A November freeze killed all crops in 1995 after only 4 weeks of sampling. During the next two years the study was initiated during the first week of September to reduce the risk of freezes.

Treatment Comparisons

Egg densities on the squash trap crop were significantly higher than on bean throughout the three years of the study (Tables 1-3). Otherwise there were no consistent trends among treatments from year to year. When treatment differences occurred, egg

and nymph densities tended to be highest on bean alone. However no treatment showed a clear advantage over bean alone in reducing densities of eggs or nymphs.

Eggs. While egg densities tended to be lowest in the two treatments containing squash in 1995 (Table 2-1), these densities were significantly lower than those in bean alone only during the second week of sampling. Egg densities tended to be highest in the reflective mulch treatment in 1995, though mean egg counts in the reflective mulch treatment were never significantly different from those on bean alone.

Egg counts in the reflective mulch treatment were 25% lower than bean alone during week 1 in 1996 (Table 2-2), and 32% lower than bean alone during the first week of sampling in 1997 (Table 2-3). There were no significant differences in egg counts among treatments during the subsequent five weeks of sampling in 1996 or 1997.

Nymphs. In 1995, there were differences in nymph densities among treatments only during the second week of sampling, when nymph densities in the mulch-and-squash treatment were significantly lower than in bean alone (Table 2-4). Nymph densities tended to be lowest in the mulch treatment when nymphs first appeared in 1996 and 1997 (Tables 5-6). However on the fifth week of sampling in 1996, nymph counts were fourteen times higher in the mulch treatment than in the squash treatment, and twelve times higher than in bean alone (Table 2-5). On the fifth week of sampling in 1997, nymph counts were significantly higher in the mulch treatment than in the three other treatments (Table 2-6).

Parasitized nymphs. No parasitism was recorded in 1995. Little parasitism was observed in 1996, and was observed only in the lower stratum. During the final week of sampling in 1996, parasitism was significantly higher in the squash treatment (0.12 ± 0.23) than in the squash/mulch treatment (0; $p < 0.05$). Parasitism was intermediate in

the mulch (0.07 ± 0.18) and bean (0.05 ± 0.16) treatments. Parasitism was much higher in 1997. Parasitized nymphs were observed in all treatments beginning with the third week in 1997 (Table 2-7). During the sixth week of sampling, mean parasitism in the bean alone treatment was 262% greater than in the mulch treatment.

Red-eyed nymphs. Red-eyed nymphs were not observed in 1995. Red-eyed nymphs were observed sporadically in 1996. During the fourth week of sampling that year, densities of red-eyed nymphs were significantly higher in the mulch treatment (0.29 ± 0.38) than in the squash treatment (0.05 ± 0.16; $p < 0.05$). Densities were intermediate in the bean (0.24 ± 0.50) and squash/mulch (0.14 ± 0.29) treatments. Red-eyed nymphs were present in all treatments from the third week of sampling in 1997 until the final week of sampling (Table 2-8). There were no significant differences in densities of red-eyed nymphs among treatments.

Stratum Comparisons

On bean, there were significant differences in density between strata only during 1996, when eggs tended to be higher in the upper stratum (Table 2-2). Nymphs in the same year tended to be higher in the lower stratum (Table 2-5). No parasitized nymphs or red-eyed nymphs were recorded in 1995, probably because of the early freeze. In the following two years low densities of parasitized or red-eyed nymphs were observed primarily in the lower stratum.

On squash, egg densities tended to be highest on younger leaves early in the season and to shift to predominance in older leaves in the last few weeks of sampling (Table 2-9). Nymphs were found primarily on the older leaves each year (Table 2-10).

Yield

Crops froze in 1995 before yield could be harvested. In 1996 yields were highest in the mulched treatments. Yields were extremely low in 1997, presumably due to high whitefly pressure (Table 2-11).

Virus

In 1996, only 1 plant (in the squash treatment) tested positive for the presence of bean golden mosaic geminivirus. Virus presence was much higher in 1997. There were no significant differences in virus presence (percent of plants testing positive for virus) among treatments (bean: 56 ± 51%; mulch: 55 ± 51%; squash: 27 ± 46%; squash/mulch: 38 ± 49%).

Discussion

Reflective Mulch

The loss of effectiveness of reflective mulch after the first week of 1996 and 1997 may be attributed to accumulation of dust on the mulch and shading by growing plants. *Bemisia tabaci* engages in most flight activity in the middle of the day (Bellows et al. 1988, Byrne and von Bretzel 1987), when mulch should be reflecting repellent UV rays. However, it is not unusual to see adults moving with early morning breezes in agricultural fields. Adults may colonize crops planted with reflective mulch before the mulch receives strong sunlight.

Most studies compare reflective plastic mulch with mulches of other colors rather than with bare soil (Csizinsky et al. 1997, Powell and Stofella 1993). Researchers generally conclude that reflective mulch is insufficient as a sole method of control (Natwick and Mayberry 1994, Schuster et al. 1989). While reflective mulch does not appear to provide season-long reduction of whitefly densities, the use of reflective mulch

has resulted in delays in the onset of virus in tomatoes (Csizinsky et al. 1997) and reduction in viral disease in tomatoes and squash (Fehmy et al. 1994).

Crops grown with plastic mulches experience reduced weed competition and increased water and nutrient availability compared to crops grown on bare soil. In our studies, crops grown with mulch were visibly more robust than crops grown on bare ground. This clearly had a direct effect on yield (Table 2-11). The improved plant quality of crops grown with mulch may have enhanced their ability to support higher populations of nymphs as was observed during week 5 of 1996 and 1997.

Trap Crop

Egg densities were consistently far higher on squash with or without mulch than on bean in the same treatments (Tables 2-1 to 2-3). However egg densities on bean planted with squash were not lower than on bean alone. This indicates that squash did not function as a trap crop.

High densities of *Bemisia* on a given crop have been interpreted as a 'preference' for that crop, in some cases leading it to be tested as a trap crop. Squash (Schuster et al. 1996), cantaloupe (*Cucumis melo* L.) (Ellsworth et al. 1994, Perring et al. 1995), soybean (*Glycine max* L.) (McAuslane et al. 1995) and Wright's groundcherry (*Physalis wrightii* Gray) (Ellsworth et al. 1994) have been tested as trap crops for *Bemisia* with unclear results. Whitefly densities on the main crop were either unaffected by the presence of the trap crop candidate, or reduced on a few isolated sampling dates, as occurred with our study. Puri et al. (1996) intercropped cotton (*Gossypium hirsutum* L.) with wild brinjal (*Solanum khasianum* Clarke), which traps arthropods with a sticky exudate, without significantly reducing *Bemisia* densities in cotton.

A successful trap crop will draw a herbivore away from the main crop before the herbivore has damaged the main crop by oviposition, feeding, or inoculation with a pathogen. The limited success achieved managing *Bemisia* with trap crops may be due to the mechanisms by which whiteflies find and accept hosts.

Whiteflies seeking hosts respond to the yellowish range of light spectra emitted by most vegetation (Mound 1962, van Lenteren and Noldus 1990, Byrne and Bellows 1991). *Trialeurodes vaporariorum*, *B. tabaci* and *Aleurocanthus woglumi* apparently do not respond to crop-specific olfactory or visual cues (van Lenteren and Noldus 1990). *Trialeurodes vaporariorum* must probe before accepting or rejecting a plant (van Sas et al. 1978, Noldus et al. 1986a). *Bemisia* also seems to require gustatory information to judge host suitability (Byrne and Bellows 1991). Examination of the precibarial and cibarial chemosensillae by Hunter et al. (1996) indicates that *B. tabaci* can test plant sap without ingesting it. This supports the notion that host discrimination by *Bemisia* occurs after the host has been tasted.

Host 'preference' by whiteflies among crops may not be apparent until after adults have invested time in colonizing the less suitable crop. *Trialeurodes vaporariorum* will leave certain acceptable hosts after a few hours, while spending days on other hosts (van Sas et al. 1978, Verschoor-van der Poel and van Lenteren 1978). Similarly, *T. vaporariorum* tends to accumulate in greater density on some hosts than others over a given time period (Verschoor-van der Poel 1978 cited in van Lenteren and Noldus 1990). If host preference for a given crop, such as a trap crop candidate, does not affect whitefly behavior until after whitefly adults have oviposited and fed on the main crop, trap cropping may have limited benefit for whitefly management.

However, Al-Musa (1982) and Schuster et al. (1996) reduced the incidence of virus in tomato (*Lycopersicon esculentum* Mill.) by trap cropping with cucumber (*Cucumis sativus* L.) and squash, respectively. Meena et al. (1984) reported a reduction in *Bemisia*-vectored yellow mosaic of moth bean (*Vigna aconitifolia* (Jacqu.) Marechal) by trap cropping with guar (*Cyanopsis tetragonoloba* (Linn.) Taub), sesame (*Sesamum indicum* L), millet (*Pennisetum typhoides* (Burm, F.) Stapf. and Hubb.) or sorghum (*Sorghum vulgare* L). The latter two crops are not hosts of *Bemisia*, however, so it is possible that a different mechanism was involved. These studies indicate that trap cropping can be used to reduce transmission of virus by whiteflies.

Conclusion

In our study squash did not function as a trap crop either by reducing density of whitefly or presence of virus on adjacent bean. Oviposition was consistently higher on squash than on bean. Oviposition was significantly less on bean in plots with reflective silver mulch during the first week of sampling in 2 of the 3 years of this study. Mulch improved plant quality and increased yield compared to unmulched plants. Neither squash, reflective mulch nor the combination of the 2 provided significantly greater protection from *B. argentifolii* than bean planted alone on bare soil.

Table 2-1. Egg density of B. argentifolii (mean ± SD /cm^2) on beans and squash, 1995

		Bean			Squash
Week	Treatment	Lower stratum	Upper stratum	Mean	Mean
1	Bean	0.37 ± 0.53	0.95 ± 0.88**ab**[1]	0.66 ± 0.78**ab**	
	Mulch	1.06 ± 0.79	0.96 ± 0.92**a**	1.01 ± 0.85**a**	
	Squash	0.53 ± 0.55	0.44 ± 0.41**bc**	0.49 ± 0.48**ab**	
	Squash/mulch	0.38 ± 0.60	0.33 ± 0.47**c**	0.36 ± 0.54**b**	
2	Bean	0.40 ± 0.48	0.63 ± 0.61**ab**	0.52 ± 0.56**a**	
	Mulch	0.80 ± 1.30	1.26 ± 1.28**a**	1.03 ± 1.30**a**	
	Squash	0.13 ± 0.24	0.13 ± 0.22**b**	0.13 ± 0.23**b**	2.80 ± 3.95**a****
	Squash/mulch	0.07 ± 0.15	0.19 ± 0.26**b**	0.13 ± 0.22**b**	1.60 ± 2.80**b****
3	Bean	0.39 ± 0.56**b**	0.40 ± 0.85	0.40 ± 0.71**ab**	
	Mulch	0.81 ± 0.75**a**	0.57 ± 0.73	0.70 ± 0.74**a**	
	Squash	0.04 ± 0.10**c**	0.11 ± 0.20	0.07 ± 0.16**b**	1.24 ± 1.83**
	Squash/mulch	0.19 ± 0.34**bc**	0.15 ± 0.38	0.17 ± 0.36**b**	0.50 ± 0.70**
4	Bean	0.12 ± 0.20	0.18 ± 0.35	0.15 ± 0.28	
	Mulch	0.32 ± 0.39	0.24 ± 0.35	0.28 ± 0.37	
	Squash	0.10 ± 0.16	0.13 ± 0.29	0.11 ± 0.23	0.51 ± 0.78**
	Squash/mulch	0.06 ± 0.15	0.08 ± 0.16	0.07 ± 0.15	0.32 ± 0.59**

[1] Means in the same column with the same letter are not significantly different according to Tukey's Studentized Range test with controlled type 1 experiment-wise error rate (a=0.05). The absence of letters in a column indicates lack of significant differences among any means. *, **indicate that mean densities in bean and squash are significantly different according to the pairwise t-test at $p < 0.05$ and $p < 0.01$, respectively.

Table 2-2. Egg density of *B. argentifolii* (mean ± SD/cm^2) on beans and squash, 1996

		Bean			Squash
Week	Treatment	Lower Stratum	Upper stratum	Mean	Mean
1	Bean	4.16 ± 3.28**a**[1]			
	Mulch	0.97 ± 1.14**c**			
	Squash	4.03 ± 1.80**ab**			0.96 ± 0.72**
	Squash/mulch	1.86 ± 1.72**bc**			0.07 ± 0.21**
2	Bean	0.69 ± 0.78	1.59 ± 0.60	1.14 ± 1.06	
	Mulch	1.71 ± 2.02	1.40 ± 0.95	1.56 ± 1.55	
	Squash	0.36 ± 0.50	1.38 ± 0.77	0.87 ± 0.82	5.19 ± 8.89*
	Squash/mulch	1.31 ± 1.59	1.19 ± 1.01	1.24 ± 1.31	5.02 ± 8.28*
3	Bean	0.45 ± 0.43	1.33 ± 0.91	0.89 ± 0.83	
	Mulch	0.33 ± 0.40	1.02 ± 0.92	0.68 ± 0.78	
	Squash	0.12 ± 0.26	0.86 ± 0.68	0.49 ± 0.63	3.67 ± 6.24*
	Squash/mulch	0.45 ± 0.44	1.19 ± 1.07	0.82 ± 0.89	6.34 ± 7.74**
4	Bean	0.02 ± 0.08	0.43 ± 0.66	0.23 ± 0.51	
	Mulch	0.17 ± 0.41	0.88 ± 0.98	0.52 ± 0.82	
	Squash	0.02 ± 0.08	0.48 ± 1.05	0.25 ± 0.77	5.00 ± 6.87**
	Squash/mulch	0.05 ± 0.11	0.43 ± 0.52	0.24 ± 0.42	3.76 ± 5.62**
5	Bean	0.31 ± 0.43	0.24 ± 0.58	0.27 ± 0.50	
	Mulch	0.86 ± 0.75	0.31 ± 0.39	0.58 ± 0.65	
	Squash	0.41 ± 0.85	0.38 ± 0.75	0.39 ± 0.79	0.51 ± 0.81
	Squash/mulch	0.29 ± 0.39	0.14 ± 0.26	0.22 ± 0.33	0.63 ± 0.93*

6	Bean	0.07 ± 0.13	0.26 ± 0.49	0.17 ± 0.37	
	Mulch	0.17 ± 0.19	0.26 ± 0.33	0.22 ± 0.27	
	Squash	0.09 ± 0.25	0.33 ± 0.29	0.21 ± 0.30	0.66 ± 0.77*
	Squash/mulch	0.14 ± 0.26	0.22 ± 0.28	0.18 ± 0.27	1.30 ± 1.89**

[1] Means in the same column with the same letter are not significantly different according to Tukey's Studentized Range test with controlled type 1 experiment-wise error rate (a=0.05). The absence of letters in a column indicates lack of significant differences among any means. *, ** indicate that mean densities in bean and squash are significantly different according to the pairwise t-test at $p < 0.05$ and $p < 0.01$, respectively.

Table 2-3. Egg density of *B. argentifolii* (mean ±SD/cm^2) on beans and squash, 1997

		Bean			Squash
Week	Treatment	Lower stratum	Upper stratum	Mean	Mean
1	Bean	15.32 ± 10.73**a**[1]			
	Mulch	4.89 ± 4.17**b**			
	Squash	9.18 ± 4.14**ab**			27.37 ± 33.31 **
	Squash/mulch	5.93 ± 3.48**b**			23.07 ± 27.53 **
2	Bean	16.77 ± 10.44	27.11 ± 13.47	21.94 ± 12.81	
	Mulch	11.25 ± 8.18	29.86 ± 15.15	20.55 ± 15.19	
	Squash	14.48 ± 10.27	34.95 ± 22.13	24.71 ± 19.74	123.71 ± 137.66**
	Squash/mulch	13.29 ± 16.62	26.46 ± 18.91	19.88 ± 18.50	134.92 ± 163.37**
3	Bean	1.71 ± 2.27#	8.50 ± 5.09#	5.11 ± 5.17	
	Mulch	0.30 ± 0.54#	15.55 ± 9.45#	7.93 ± 10.19	
	Squash	2.39 ± 3.49	7.36 ± 6.80	4.88 ± 5.82	47.52 ± 58.68**
	Squash/mulch	0.36 ± 0.62#	12.87 ± 11.16#	6.61 ± 10.00	45.70 ± 44.85**
4	Bean	0.25 ± 0.27#	7.73 ± 9.04#	3.99 ± 7.28	
	Mulch	0.55 ± 0.78#	11.45 ± 11.36#	6.00 ± 9.60	
	Squash	0.39 ± 0.85#	6.29 ± 4.01#	3.34 ± 4.14	36.22 ± 33.11**
	Squash/mulch	0.36 ± 0.45#	7.71 ± 2.46#	4.04 ± 4.17	24.09 ± 21.08**
5	Bean	0.57 ± 1.29	3.45 ± 3.59	2.01 ± 3.00	
	Mulch	0.75 ± 1.55#	10.39 ± 13.21#	5.57 ± 10.37	
	Squash	0.09 ± 0.20#	8.43 ± 4.50#	4.26 ± 5.29	37.67 ± 36.67**
	Squash/mulch	0.11 ± 0.17#	7.52 ± 7.57#	3.81 ± 6.43	46.50 ± 37.98**

6	Bean	0.04 ± 0.07	0.88 ± 0.74	0.46 ± 0.67	
	Mulch	0.02 ± 0.05	1.80 ± 3.14	0.91 ± 2.34	
	Squash	0	0.82 ± 1.25	0.41 ± 0.96	17.05 ± 16.74**
	Squash/mulch	0.07 ± 0.20	0.91 ± 0.60	0.49 ± 0.61	20.24 ± 18.00**

[1] Means in the same column with the same letter are not significantly different according to Tukey's Studentized Range test with controlled type 1 experiment-wise error rate (a=0.05). The absence of letters in a column indicates lack of significant differences among any means. *, ** indicate that mean densities in bean and squash are significantly different according to the pairwise t-test at $p < 0.05$ and $p < 0.01$, respectively. # indicates that upper and lower stratum means are significantly different according to the pair-wise t-test at $p < 0.05$.

Table 2-4. Nymph density of *B. argentifolii* (mean ± SD/cm^2) on beans and squash, 1995

		Bean			Squash
Week	Treatment	Lower stratum	Upper stratum	Mean	Mean
1	Bean	0.20 ± 0.59	0.11 ± 0.29	0.15 ± 0.46	
	Mulch	0.15 ± 0.29	0.25 ± 0.62	0.20 ± 0.48	
	Squash	0.18 ± 0.36	0.33 ± 0.50	0.26 ± 0.44	
	Squash/mulch	0.13 ± 0.34	0.06 ± 0.17	0.10 ± 0.27	
2	Bean	0.96 ± 0.84**a**[1]	0	0.48 ± 0.76**a**	
	Mulch	0.42 ± 0.36**ab**	0.20 ± 0.35	0.30 ± 0.37**ab**	
	Squash	0.21 ± 0.27**b**	0.07 ± 0.17	0.14 ± 0.24**ab**	0.16 ± 0.77
	Squash/mulch	0.21 ± 0.40**b**	0.04 ± 0.10	0.13 ± 0.30**b**	0**
3	Bean	0.27 ± 0.47[2]	0[2]	0.14 ± 0.35	
	Mulch	0.25 ± 0.40	0	0.13 ± 0.31	
	Squash	0.06 ± 0.15	0	0.03 ± 0.11	0.20 ± 0.75
	Squash/mulch	0.05 ± 0.14	0.02 ± 0.08	0.04 ± 0.11	0.07 ± 0.27
4	Bean	0.13 ± 0.24	0	0.07 ± 0.18	
	Mulch	0.20 ± 0.57	0	0.10 ± 0.41	
	Squash	0.01 ± 0.06	0	0.01 ± 0.04	0.13 ± 0.56
	Squash/mulch	0.01 ± 0.06	0	0.01 ± 0.04	0.32 ± 1.04*

[1] Means in the same column with the same letter are not significantly different according to Tukey's Studentized Range test with controlled type 1 experimentwise error rate (a=0.05). The absence of letters in a column indicates lack of significant differences among any means. [2] Upper and lower stratum means are significantly different according to the pair-wise t-test at $p < 0.10$. *, ** indicate that nymph densities were significantly different between bean and squash at $p < 0.05$ and $p < 0.01$ according to the pairwise t-test.

Table 2-5. Nymph density of *B. argentifolii* (mean ± SD/cm^2) on bean and squash, 1996

		Bean			Squash
Week	Treatment	Lower stratum	Upper stratum	Mean	Mean
2	Bean	0.52 ± 0.57	0.57 ± 0.60**ab**[1]	0.55 ± 0.57**a**	
	Mulch	0.05 ± 0.16	0.19 ± 0.33**a**	0.12 ± 0.27**b**	
	Squash	0#	1.28 ± 0.87**b**#	0.64 ± 0.89**a**	0**
	Squash/mulch	0	0.29 ± 0.30**a**	0.14 ± 0.25**b**	0.01 ± 0.06*
3	Bean	2.29 ± 1.36#	0.36 ± 0.49#	1.32 ± 1.40	
	Mulch	2.31 ± 1.52#	0.62 ± 1.33#	1.46 ± 1.64	
	Squash	1.97 ± 1.13#	0.21 ± 0.28#	1.10 ± 1.21	1.01± 2.40
	Squash/mulch	1.86 ± 1.02#	0.31 ± 0.39#	1.08 ± 1.09	0.63 ± 1.33
4	Bean	1.41 ± 0.86#	0.33 ± 0.56#	0.87 ± 0.90**a**	
	Mulch	1.76 ± 1.51#	0.19 ± 0.43#	0.98 ± 1.35**a**	
	Squash	0.83 ± 0.70	0.79 ± 0.88	0.81 ± 0.78**ab**	0.12 ± 0.58**
	Squash/mulch	0.86 ± 0.89	0.02 ± 0.08	0.44 ± 0.75**b**	0.25 ± 0.63
5	Bean	0.17 ± 0.19	0	0.08 ± 0.16**a**	
	Mulch	0.55 ± 0.51	0.02 ± 0.08	0.29 ± 0.45**b**	
	Squash	0.05 ± 0.11	0	0.02 ± 0.08**a**	0.37 ± 1.22
	Squash/mulch	0.17 ± 0.33	0.10 ± 0.19	0.13 ± 0.27**ab**	0.42 ± 1.21
6	Bean	0.41 ± 0.51	0	0.20 ± 0.41	
	Mulch	1.05 ± 1.32#	0#	0.52 ± 1.06	
	Squash	0.26 ± 0.28	0	0.13 ± 0.24	0.27 ± 1.05
	Squash/mulch	0.50 ± 0.61	0.07 ± 0.25	0.29 ± 0.51	0.16 ± 0.45

[1] Means in the same column with the same letter are not significantly different according to Tukey's Studentized Range test with controlled type 1 experimentwise error rate (a=0.05). The absence of letters in a column indicates lack of significant differences among any means. *, ** indicate that mean densities in bean and squash are significantly different according to the pairwise t-test at $p < 0.05$ and $p < 0.01$, respectively. # indicates that upper and lower stratum means are significantly different according to the pair-wise t-test at $p < 0.05$.

Table 2-6. Nymph density of *B. argentifolii* (mean ± SD/cm^2) on bean and squash, 1997

		Bean			Squash
Week	Treatment	Lower stratum	Upper stratum	Mean	Mean
2	Bean	8.29 ± 4.81#	0.68 ± 1.26#	4.48 ± 5.19**ab**[1]	
	Mulch	3.03 ± 1.38	1.20 ± 2.23	2.12 ± 2.03**b**	
	Squash	11.09 ± 6.82#	2.66 ± 7.24#	6.87 ± 8.07**a**	12.47 ± 24.15
	Squash/mulch	5.98 ± 3.62	0.39 ± 0.69	3.19 ± 3.83**ab**	6.25 ± 10.40
3	Bean	13.16 ± 12.04	10.50 ± 18.06	11.70 ± 14.91	
	Mulch	7.54 ± 3.26	3.21 ± 5.12	5.38 ± 4.71	
	Squash	12.84 ± 7.54	10.18 ± 13.88	11.51 ± 10.88	61.69 ± 176.54
	Squash/mulch	6.97 ± 3.92	6.05 ± 7.68	6.51 ± 5.91	13.04 ± 32.00
4	Bean	3.59 ± 2.77	4.32 ± 4.75	3.96 ± 3.78	
	Mulch	6.12 ± 7.10	2.50 ± 4.91	4.30 ± 6.19	
	Squash	3.34 ± 2.77	6.70 ± 12.52	5.02 ± 8.93	14.98 ± 29.31@
	Squash/mulch	2.46 ± 1.55	0.02 ± 0.05	1.24 ± 1.65	5.51 ± 13.60
5	Bean	0.95 ± 0.91	3.29 ± 3.41**ab**	2.12 ± 2.69**b**	
	Mulch	7.89 ± 5.52	11.29 ± 9.09**a**	9.59 ± 7.47**a**	
	Squash	1.93 ± 1.99	0.50 ± 1.03**b**	1.21 ±1.70**b**	3.35 ± 6.14**a**
	Squash/mulch	2.55 ± 2.78	1.84 ± 2.31**ab**	2.20 ± 2.49**b**	0.79 ± 1.93**b**
6	Bean	0.89 ± 1.03	2.86 ± 2.98	1.88 ± 2.38	
	Mulch	0.86 ± 0.99	4.05 ± 5.22	2.46 ± 3.99	
	Squash	0.48 ± 0.44	4.92 ± 5.26	3.33 ± 4.07	24.89 ± 40.84**
	Squash/mulch	2.21 ± 2.61	3.27 ± 6.27	2.74 ± 4.68	16.49 ± 29.18

[1]Means in the same column with the same letter are not significantly different according to Tukey's Studentized Range test with controlled type 1 experimentwise error rate (a=0.05). The absence of letters in a column indicates lack of significant differences among any means. *, ** indicate that mean densities in bean and squash are significantly different according to the pairwise t-test at $p < 0.05$ and $p < 0.01$, respectively. # indicates that upper and lower stratum means are significantly different according to the pair-wise t-test at $p < 0.05$.

Table 2-7. Parasitized nymph density (mean ± SD/cm^2) of *B. argentifolii* on bean, 1997

Week	Treatment	Lower stratum	Upper stratum	Mean
3	Bean	0.32 ± 0.36	0	0.16 ± 0.29
	Mulch	0.25 ± 0.28	0	0.13 ± 0.23
	Squash	0.13 ± 0.19	0	0.06 ± 0.15
	Squash/mulch	0.34 ± 0.37	0	0.17 ± 0.31
4	Bean	0.61 ± 0.55	0.02 ± 0.05	0.31 ± 0.48
	Mulch	0.61 ± 0.70	0.02 ± 0.05	0.31 ± 0.57
	Squash	0.89 ±0.86#	0.11 ± 0.30#	0.50 ± 0.74
	Squash/mulch	0.34 ± 0.42	0	0.17 ± 0.33
5	Bean	0.41 ± 0.67	0.02 ± 0.05	0.21 ± 0.50
	Mulch	1.00 ± 0.92#	0.09 ± 0.25#	0.54 ± 0.80
	Squash	0.79 ± 0.67#	0#	0.39 ± 0.61
	Squash/mulch	0.70 ± 0.97	0	0.34 ± 0.75
6	Bean	0.48 ± 0.59	0.20 ± 0.56	0.34 ± 0.57**a**[1]
	Mulch	0.25 ± 0.50	0	0.13 ± 0.37**b**
	Squash	0.48 ± 0.44	0	0.24 ± 0.39**ab**
	Squash/mulch	0.45 ± 0.76	0.04 ± 0.10	0.24 ± 0.57**ab**

[1] Means in the same column with the same letter are not significantly different according to Tukey's Studentized Range test with controlled type 1 experimentwise error rate (a=0.05). The absence of letters in a column indicates lack of significant differences among any means. # indicates that upper and lower stratum means are significantly different according to the pair-wise t-test at $p < 0.05$.

Table 2-8. Red-eyed nymph density (mean ± SD/cm^2) of *B. argentifolii* on bean, 1997

Week	Treatment	Lower stratum	Upper stratum	Mean
3	Bean	0.43 ± 0.60	0	0.21 ± 0.47
	Mulch	0.32 ± 0.50	0	0.16 ± 0.38
	Squash	0.14 ± 0.30	0	0.07 ± 0.22
	Squash/mulch	0.46 ± 0.48	0	0.23 ± 0.41
4	Bean	0.71 ± 1.08	0	0.36 ± 0.82
	Mulch	0.20 ± 0.44	0	0.10 ± 0.32
	Squash	0.68 ± 0.77	0.02 ± 0.05	0.35 ± 0.63
	Squash/mulch	0.38 ± 0.40	0	0.19 ± 0.34
5	Bean	0.55 ± 1.45	0	0.28 ± 1.03
	Mulch	1.13 ± 1.38#	0.18 ± 0.51#	0.65 ± 1.11
	Squash	0.22 ± 0.30	0	0.11 ± 0.23
	Squash/mulch	0.46 ± 0.87	0.04 ± 0.10	0.25 ± 0.63
6	Bean	0.41 ± 0.48	0.04 ± 0.10	0.22 ± 0.39
	Mulch	0.09 ± 0.20	0	0.04 ± 0.14
	Squash	0.34 ± 0.37	0	0.10 ± 0.22
	Squash/mulch	0.20 ±	0	0.17 ± 0.31

# indicates that upper and lower stratum means are significantly different according to the pair-wise t-test at $p < 0.05$.

Table 2-9. Egg density (mean ± SD/cm^2) of *B. argentifolii* by stratum on squash.

Year	Week	Treatment	Lower stratum	Upper stratum
1995	2	Squash	1.00 ± 1.67@	4.61 ± 4.72@
		Squash/mulch	0.14 ± 0.28	3.05 ± 3.40
	3	Squash	2.15 ± 2.20@	0.33 ± 0.48@
		Squash/mulch	0.83 ± 0.81#	0.16 ± 0.34#
	4	Squash	0.92 ± 0.92#	0.10 ± 0.20#
		Squash/mulch	0.60 ± 0.74#	0.05 ± 0.14#
1996	1	Squash	0.96 ± 0.72	
		Squash/mulch	0.07 ± 0.21	
	2	Squash	0.02 ± 0.08#	10.36 ± 10.35#
		Squash/mulch	0.14 ± 0.33#	9.91 ± 9.56#
	3	Squash	1.98 ± 2.11	5.35 ±. 8.41
		Squash/mulch	2.36 ± 2.21	10.33 ± 9.52
	4	Squash	2.07 ± 4.23#	7.93 ± 7.88#
		Squash/mulch	1.17 ± 1.43@	6.36 ± 7.02@
	5	Squash	0.31 ± 0.67	0.72 ± 0.92
		Squash/mulch	0.36 ± 0.70	0.91 ± 1.07
	6	Squash	0.64 ± 0.72	0.67 ± 0.84
		Squash/mulch	1.50 ± 2.45	1.10 ± 1.15

1997	1	Squash	0.73 ± 0.39#	54.00 ± 27.50#
		Squash/mulch	0.11 ± 0.17#	46.03 ± 20.47#
	2	Squash	0.18 ± 0.26#	247.25 ± 75.65#
		Squash/mulch	0.07 ± 0.07#	269.77 ± 125.02#
	3	Squash	78.16 ± 67.16#	16.88 ± 26.85#
		Squash/mulch	70.32 ± 37.31#	21.09 ± 39.17#
	4	Squash	46.95 ± 42.90	25.50 ± 15.70
		Squash/mulch	11.02 ± 18.10	14.00 ± 14.04
	5	Squash	66.31 ± 30.69#	9.04 ± 8.14#
		Squash/mulch	70.21 ± 34.20	22.79 ± 25.22
	6	Squash	24.86 ± 19.28	7.95 ± 6.50
		Squash/mulch	25.50 ± 17.85	14.98 ± 18.10

# indicates that upper and lower stratum means are significantly different according to the pair-wise t-test at $p < 0.05$. @ indicates that upper and lower stratum means are significantly different according to the pair-wise t-test at $p < 0.10$.

Table 2-10. Nymph density (mean ± SD/cm^2) on *B. argentifolii* by stratum on squash.

Year	Week	Treatment	Lower stratum	Upper stratum
1995	2	Squash	0.13 ± 0.58	0.19 ± 0.93
		Squash/mulch	0	0
	3	Squash	0.39 ± 1.04	0.01 ± 0.06
		Squash/mulch	0.13 ± 0.37	0
	4	Squash	0.26 ± 0.78	0
		Squash/mulch	0.64 ± 1.41	0
1996	2	Squash	0	0
		Squash/mulch	0	0.02 ± 0.08
	3	Squash	2.02 ± 3.13#	0#
		Squash/mulch	1.26 ± 1.69#	0#
	4	Squash	0.24 ± 0.83	0
		Squash/mulch	0.45 ± 0.84	0.05 ± 0.16
	5	Squash	0.74 ± 1.68	0
		Squash/mulch	0.83 ± 1.64	0
	6	Squash	0.45 ± 1.48	0.10 ± 0.19
		Squash/mulch	0.31 ± 0.04	0

1997	1	Squash	0.07 ± 0.20	0
		Squash/mulch	0.02 ± 0.05	0
	2	Squash	0.04 ± 0.10	24.91 ± 29.94
		Squash/mulch	0.04 ± 0.10	12.46 ± 11.98
	3	Squash	105.80 ± 247.56	17.57 ± 32.49
		Squash/mulch	20.45 ± 42.59	5.64 ± 15.96
	4	Squash	29.96 ± 36.44	0
		Squash/mulch	11.02 ± 18.09	0
	5	Squash	6.70 ± 7.44	0
		Squash/mulch	1.59 ± 2.56	0
	6	Squash	38.96 ± 49.21	5.20 ± 11.15
		Squash/mulch	29.48 ± 37.37	3.50 ± 8.43

# indicates that upper and lower stratum means are significantly different according to the pair-wise t-test at $p < 0.05$.

Table 2-11. Total bean yield (kg).

Year	Treatment	Total bean yield (kg/plot)
1996	Bean	6.22**b**[1]
	Mulch	15.68**a**
	Squash	4.52**bc**
	Squash/mulch	11.42**ab**
1997	Bean	0.57
	Mulch	0.68
	Squash	0
	Squash/mulch	1.24

[1] Means in the same column with the same letter are not significantly different according to Tukey's Studentized Range test with controlled type 1 experimentwise error rate (a=0.05). The absence of letters in a column indicates the lack of significant differences among any means.

CHAPTER 3
POTENTIAL OF FIELD CORN (*ZEA MAYS* L.) AS A BARRIER CROP AND EGGPLANT (*SOLANUM MELONGENA L.*) AS A TRAP CROP FOR MANAGEMENT OF THE SILVERLEAF WHITEFLY, *BEMISIA ARGENTIFOLII* (HOMOPTERA: ALEYRODIDAE) ON BEAN *(PHASEOLUS VULGARIS* L.) IN NORTH FLORIDA

Introduction

Bemisia argentifolii Bellows & Perring, the silverleaf whitefly (also known as *Bemisia tabaci* strain B (Gennadius)), causes significant economic damage to agronomic and horticultural crops throughout warm regions of the world (Brown et al. 1995). *Bemisia argentifolii* is a phloem-feeder which vectors numerous geminiviruses and inflicts a variety of plant disorders as well as mechanical damage (Byrne et al. 1990, Hiebert et al. 1996, Shapiro 1996). *Bemisia* has demonstrated resistance to most classes of pesticides (Denholm et al. 1996), forcing growers and reseachers to evaluate alternative methods of control. Attempts to manage whiteflies by cultural means have included the use of trap crops (Al-Musa 1982, Ellsworth et al. 1994, McAuslane et al. 1995, Schuster et al. 1996) and barrier crops (Fargette and Fauquet 1988, Morales et al. 1993, Rataul et al. 1989, Sharma and Varma 1984).

Trap crops are preferred host plants which are used to draw an herbivore away from a less-preferred main crop (Vandermeer 1989). *Bemisia argentifolii* has been observed to oviposit heavily on eggplant (*Solanum melongena* L.), leading researchers to suggest eggplant as a promising trap crop candidate (Faust 1992).

Whiteflies are weak fliers, relying on air currents for both short and long distance migration (Byrne and Bellows 1991, Byrne et al. 1996). Several tall-growing non-host

plants, primarily in the family Gramineae, have been tested as barrier crops or intercrops to reduce whitefly colonization and virus transmission among main crops. Results have been mixed. Morales et al. (1993) reported that a sorghum (*Sorghum bicolor* (L.) Moench) barrier reduced *Bemisia* densities, but not transmission of virus, on tomatos (*Lycopersicon esculentum* Mill.). A pearl millet (*Pennisetum typhoides* (Burm. f.) Stapf & Hubbard) barrier reduced whitefly virus transmission on cowpea (*Vigna unguiculata* (L.) Walp.) (Sharma and Varma 1984) and soybean (*Glycine max* (L) Merrill) (Rataul et al. 1989). Gold et al. (1990) found reduced densities of *Aleurotrachelis socialis* Bondar and *Trialeurodes variabilis* (Quaintance) on cassava (*Manihot esculenta* Crantz) intercropped with maize (*Zea mays* L.) and cowpea, but attributed this in part to reduced host quality due to intercrop competition. Fargette and Farquet (1988), whose study included the effect of wind direction, found densities of *B. tabaci* and virus incidence were sometimes higher on cassava intercropped with maize than on monocropped cassava.

These studies have been carried out primarily in the tropics, where safe, inexpensive cultural control measures are a priority for low resource farmers. Extension material from Central America promotes the use of crop barriers as a component of whitefly management programs (Salguero 1993; Pan-American School of Agriculture (Zamorano) poster: 'Reconozca y controle la mosca blanca'). The present study was undertaken in 1996 to test the usefulness of eggplant as a trap crop and field corn as a barrier crop for management of *B. argentifolii* on snap bean (*Phaseolus vulgaris* L.). It was continued in 1997 focusing only on the barrier crop treatment and including the effects of wind direction and barrier row orientation.

Materials and Methods

1996

Research design and plot management. The experiment was carried out at the University of Florida Green Acres Agronomy Research Farm northwest of Gainesville, FL (29°40'N, 82°30'W). Four treatments were compared: 1) bean planted in monoculture, 2) bean intercropped with eggplant, 3) bean intercropped with field corn, and 4) bean monoculture treated with imidacloprid (Provado 1.6F, Bayer, Kansas City, MO), a systemic insecticide. The imidacloprid treatment was included for yield comparison only. It was not sampled for whiteflies.

Crop varieties used were 'Espada' garden bean (Harris Seed, Rochester, NY), 'Black Beauty' eggplant (Ferry-Morse Seed, Fulton, KY), and the subtropical field corn hybrid Howard IIIST (Gallaher et al. 1998). Plant spacing within the row was 10 cm for bean, 15 cm for corn and 46 cm for eggplant. Each plot contained 14 rows, 6.1 m in length with 0.9 m between rows. Monoculture bean plots contained only beans. Intercropped plots were planted in a 2:4:2:4:2 pattern, with corn or eggplant in the outermost and central 2 rows, surrounding 2 four-row patches of bean. Each treatment was replicated 5 times and arranged in a randomized complete block design.

Corn was planted 26 July and fertilized with 0.68 kg 15-0-14 (N-P_2O_5-K_2O) per row. Corn received 0.3 kg 15-0-14 per row on 9 August. Heavy *Spodoptera frugiperda* (JE Smith) damage threatened the barrier crop treatment in August. Corn was treated with 1.74 liter/ha methomyl (Lannate, DuPont Corp., Newark, DE) on 9 August and 29 August. Eggplant was transplanted 22 August when 3 wks old. Eggplant received 0.23 kg per row 15-0-14 fertilizer 27 August, and 0.8 kg on 27 September and 10 October.

Beans were planted 15 September and fertilized with 0.37 kg 15-0-14 per row on 23 September and 12 October.

The experimental area was treated with 0.19 liter/ha paraquot (Gramoxone, Zeneca) on 26 July. Subsequent weed control was mechanical or by hand. The imidacloprid-treated beans received 52.6 g/ha ai imidacloprid on 4 October and 12 October. This is the recommended rate for most vegetables. Imidacloprid is not registered for use on beans but was included so that yield from intercropping treatments could be compared with yield from chemically-protected beans.

Sampling. Whole plant examinations were made of 1 or 2 bean plants per plot each week from 22 September through 11 November except for 29 September. Only the underside of the leaf was examined. The area of each leaf was recorded using a LI-COR portable leaf area meter (model LI-3000A, LI-COR Inc., Lincoln, NE). Bean treatment comparisons were made on the basis of whole plant counts. Leaf counts from upper, middle, and lower plant strata were used for comparison with eggplant on 21 October and 4 November. On 29 September bean and eggplant comparisons were based on the average of counts taken from one 3.35 cm^2 disc from a leaf in the upper and lower stratum of two plants per plot (McAuslane et al. 1995).

Whole plant examinations were made of 1 to 3 eggplants per block each week from 25 August through 8 October. After that time, plants became too large for whole plant examinations. Whole leaf counts from upper, middle and lower strata were made of eggplant on 21 October and 4 November.

Leaves were examined using a stereoscope and fiber-optic light. Total number of *B. argentifolii* eggs, nymphs, parasitized nymphs, and red-eyed nymphs (pharate adults) was recorded for each leaf. Leaves with nymphs showing symptoms of parasitism were

placed in unwaxed cylindrical 0.95 liter cardboard cartons (Fonda Group Inc., Union, NJ) to allow parasitoids to emerge.

Corn height. The height of five corn plants per row was measured on 4 October to assess the barrier effect.

Yield. Bean was harvested from two 2.0-m sections from each plot on 22 November. Fresh weight was recorded.

Statistical analysis. Densities of *B. argentifolii* eggs, nymphs, parasitized nymphs and red-eyed nymphs were compared among bean treatments using analysis of variance (PROC GLM, SAS version 6.11, SAS Institute 1996). Densities of whitefly immatures on bean and eggplant in the trap crop test were compared using the same test, as was bean yield. When appropriate, mean separation was carried out using Tukey's Studentized Range test.

1997

Research design and plot management. In 1997 the corn barrier treatment was repeated on a larger scale. Three treatments were compared to evaluate the influence of the barrier crop and the effect of barrier row orientation to wind direction on adult whitefly movement. Prevailing winds in August in the area tend to be from the east. The treatments were 1) bean planted in monoculture ('bean alone'), 2) alternating rows of bean and corn planted north to south ('barrier') and 3) alternating rows of bean and corn planted east to west ('open') (Figure 3-1).

Treatments were arranged in a randomized complete block strip split plot design. Each treatment was replicated four times. The four blocks were arranged in pairs on either side of a 12 m-wide path running north to south. Treatment plots were 15.25 m x

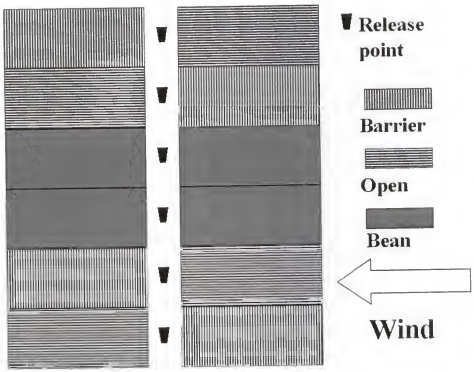

Figure 3-1. Plot Plan, Green Acres 1997

30.5 m, with the shorter side parallel to the central path. This design was used to allow for a release of whitefly adults from points spaced evenly along the central path.

Corn was planted 25 March. It was fertilized with 67 kg/ha 15-0-14 (N- P_2O_5-K_2O) on 1 April, 26 April and 14 May. Bean was planted 1 July and fertilized with 33 kg/ha 15-0-14 (N-P_2O_5-K_2O) at planting, on 10 July and 20 July. Overhead irrigation was used to supplement rainfall. Plots were weeded mechanically and by hand.

Mass-rearing of *B. argentifolii*. About 30 senescing broccoli (*Brassica olerecea* L.) plants infested with *B. argentifolii* were removed from an organic farm near Gainesville on 1-6 June. They were potted and placed with 36 flowering hibiscus (*Hibiscus rosa-sinensis* L.) plants in a greenhouse at the Department of Entomology and Nematology at the University of Florida. Hibiscus plants were watered regularly and fertilized with Purcell's Sta-Green® plant food (18-6-12 N-P_2O_5-K_2O) (Purcell Industries, Inc., Sylacauga, AL). By early August, the hibiscus plants were heavily infested with whiteflies.

Trap preparation. Yellow sticky traps have been used in many instances to monitor and sample whitefly adults (Ekbom and Rumei 1990). In the evening of 7 August, 180 plastic yellow 710-ml Solo Party cups (Solo Cup Company, Urbana, IL) were coated with Tangle-Trap Insect Trap Coating (product 95010, Tanglefoot Company, Grand Rapids, MI), an aerosol adhesive, for use as whitefly traps. The traps were arranged in 5 rows within each plot at 1.5, 7.6, 14, 20, and 26 m from the edge of the plot bordering the central path. Three traps were placed in each row. One trap was placed 3.8 m in from either side of the plot, and one was placed 7.6 m within the plot, at the center of the row.

Dust-and-release procedure. Byrne et al. (1996) developed a method of dusting whitefly adults with a fluorescent pigment in the field and trapping them at a distance as a means to monitor movement. We modified this method to distinguish the released whitefly adults which were caught on the traps from trapped members of the naturally-occurring field population.

Before dawn on 8 August the infested hibiscus plants were enclosed in 113.5 liter plastic leaf litter bags. The nozzle of a Lesco technical duster (product 1964, Lesco Inc., Cleveland, OH) was forced through the plastic and approximately 8.5-14 g Day-Glo Fire Orange fluorescent AX-14-N pigment (Day-Glo Color Corp., Cleveland, OH) was puffed from the duster into the bag onto the infested plants. The hibiscus plants were transported to the experimental area enclosed in plastic bags and arranged in 6 clusters of 6 plants along the central path and between pairs of treatment plots. The plastic bags were removed between 7:30 and 7:50 AM to allow a unified release of dyed whitefly adults. The traps were removed and replaced at dusk. The second set of traps was removed at dusk on 9 August. After removal, traps were kept refrigerated until examined.

On 10 August, the hibiscus plants were returned to the greenhouse. Traps were placed in the plots from 8:00 AM to 5:00 PM on 14 August to determine that whitefly adults from the first release were no longer measurably present in the area. On 24 August the dust-and-release procedure was repeated. Traps were set out from 8:00 AM to 8:00 PM on 24 August, and replaced with traps that were recovered at dusk on 25 August. Hibiscus plants were removed after the second set of traps had been retrieved. Traps were examined using a Spectroline 365 nm black light (model B-14N, Spectronics Corp., Westbury, NY). The number of fluorescing whitefly adults on each trap was recorded.

Corn height. The height of 15 corn plants per plot was measured on 27 August to evaluate the barrier effect.

Statistical analysis. The effect of treatment, block, and trap position on trap count was analyzed using analysis of variance (PROC GLM, SAS version 6.11, SAS Institute 1996). Orthogonal contrasts were then used to compare trap counts in the same treatment east and west (upwind and downwind) of the release point, and to compare trap counts among treatments in blocks west of the release point. Wind direction data collected at the site were provided by Dr. E. B. Whitty, Agronomy Department, University of Florida, Gainesville, FL.

Results and Discussion

1996

Whitefly densities. Densities of eggs were highest on bean when sampling began and declined over subsequent weeks (Table 3-1). Nymph densities were highest during weeks 3 and 4. Observations of parasitized nymphs and red-eyed nymphs were low throughout, although parasitism increased slightly over time.

There were no differences ($p < 0.10$) in egg density among treatments during the first six weeks of sampling. Egg densities on bean alone were higher ($p < 0.05$) than on bean intercropped with corn or eggplant during weeks 7 and 8. No differences ($p < 0.10$) in nymph densities occurred among treatments. Densities of red-eyed nymphs were higher ($p < 0.05$) on bean alone than on the corn and eggplant treatments during week 4. During week 6, parasitism was higher ($p < 0.1$) in the corn treatment than in the bean alone treatment. During week 7, parasitism was more than twice as high in the eggplant treatment as in the other two treatments.

Whitefly adults were observed on eggplant the day following transplanting on 22 August, and eggs were observed in the 25 August sample (Table 3-2). When bean plants were emerging, eggplants were quite large: they had an average of 7.0 ± 1.3 branches, a mean height of 17.33 ± 0.28 cm and mean leaf area of 485 ± 156 cm^2 (n=5).

Bean vs. eggplant. Densities of eggs and nymphs peaked on eggplant 4 weeks after transplanting and declined during the following weeks (Table 3-2). Egg densities were one and a half times higher on eggplant than on bean during the first week that bean was sampled (22 September). On all subsequent sampling dates, however, egg densities were significantly higher on bean than on eggplant.

During the week that nymphs were first observed on bean, densities were significantly lower on bean than on eggplant. During subsequent sampling dates, nymph densities were either higher on bean or not statistically different. Observations of parasitized and red-eyed nymphs were either higher on eggplant than on bean or not significantly different on the two hosts.

Parasitoid species. All parasitoids reared from bean and eggplant were hymenopterans from the family Aphelinidae.

Thirty-nine parasitoid individuals were recovered from bean leaves. Thirty-two of these were *Encarsia nigricephala* Dozier (82%), 4 were *Eretmocerus* sp. (10.3%), and 3 were *Encarsia pergandiella* Howard (7.7%).

One hundred twenty-one parasitoid individuals were reared from eggplant leaves. Fifty-one of these were *Encarsia pergandiella* (42.1%), 48 were *Encarsia nigricephala* (39.7%), 13 were *Eretmocerus* sp. (10.7%), 6 were *Encarsia transvena* (Timberlake) (5%), and 3 were *Encarsia* sp. (2.5%).

The greater parasitism and variety of parasitoid species on eggplant may be due to the greater number of weeks that eggplant was in the field.

Bean yield. Bean yield per 2 m of row was not different among the three treatments and the imidacloprid-treated bean plants (imidacloprid: 0.95 kg ± 0.71; bean: 0.87 kg ± 0.58; corn: 0.47 kg ± 0.28; eggplant: 1.14 kg ± 0.77).

Eggplant as a trap crop. Eggplant did not reduce oviposition on adjacent bean early in the season, and so did not function as a trap crop. Oviposition was not consistently higher on eggplant than on bean as reported elsewhere (Tsai and Wang 1996). Eggplant leaves may have been less suitable for oviposition because they were several weeks older than the bean leaves. Treatment differences were not statistically significant, but egg densities tended to be higher on bean planted with eggplant than on the other bean treatments during the first weeks of sampling. Proximity to colonized eggplant may tend to increase rather than decrease oviposition on bean.

A concurrent test of squash (*Cucurbita pepo* L.) as a trap crop for whiteflies also produced negative results (Smith et al., unpublished). It is possible that host-finding mechanisms used by whitefly adults prevent them from being drawn away from one host plant by the presence of another. *Bemisia* does not respond to host-specific visual or olfactory cues (Mound 1962). It apparently requires gustatory information in order to accept or reject a host (van Lenteren and Noldus 1990). Whitefly adults tend to leave some host plant species more quickly than others (Verschoor-van der Poel 1978). The observed differences in host-specific oviposition density by *Bemisia* may be due to length of tenure on the plant rather than to some preference expressed in the host-finding stage.

Many trap crop studies have not resulted in consistent reductions of whitefly densities on the main crop (Ellsworth et al. 1994, McAuslane et al. 1995, Perring et al.

1995, Puri et al. 1995, Schuster et al 1996). However, Al-Musa (1982) and Schuster et al. (1996) reported a reduction in virus incidence on tomato (*Lycopersicon esculentum* Mill.) using cucumber (*Cucumis sativus* L.) and squash, respectively, as trap crops.

Corn as a barrier crop. The corn did not grow well in 1996 due to insufficient fertilizer. It attained a mean height of 1.18 m ± 0.34 (n = 150) and a density of 27 ± 7 plants per 6.1m row (n = 30). We decided to re-evaluate the barrier effect in 1997 with larger, properly fertilized plots. Eggplant did not appear to be a promising trap crop, and so was not included in the field experiment the following year.

1997

Release of adult whiteflies. Average corn height was 2.45 ± 1.97 m when whitefly releases were made. The effect of treatment on trap count was not significant ($p < 0.10$) on any of the four collection dates (Table 3-3). The block effect was highly significant, and the interaction between treatment and block was significant or highly significant on three of the collection dates. Wind direction was from the east or northeast during the 4 days that collections were made (Table 3-4). Trap counts in plots to the west of the release point were significantly higher than trap counts in plots to the east of the release point for each treatment on each collection date (Table 3-4). When treatments were compared on the basis of downwind plots only, counts were significantly lower in the barrier treatment than in the other two treatments on two of the four collection dates. Wind direction appeared to be the primary factor determining where whitefly adults were trapped. This is consistent with observations that whitefly adults move passively with wind currents as 'aerial plankton' (Byrne and Bellows 1991). Among downwind plots, the barrier treatment tended to have the lowest counts, indicating that the arrangement of corn rows perpendicular to the prevailing wind direction did have some effect on the

movement of adults within the plot. However the overall trap counts in this study were low. The contribution made by corn barriers to reducing whiteflies may depend on the density of the whitefly population. Crop barriers such as corn may be more effective when used with other control measures. Short of employing manufactured barriers such as floating row covers or fine mesh screens, whitefly adults probably cannot be excluded from a cropped area (Norman et al. 1993).

Trap position had a significant effect on trap count (Table 3-3). The number of whiteflies caught decreased as trap distance from the release point increased. The interaction of treatment and trap position interaction was not significant, suggesting that this decline was not different among treatments.

Data derived from attractive traps may be ambiguous. A gravid or hungry whitefly adult which is surrounded by non-hosts, such as corn, may be more sensitive to a distant patch of bright yellow than an adult in similar condition surrounded by acceptable hosts, such as bean. It is conceivable that the whitefly adults in the corn treatments spent more time searching and so were drawn from a greater area than the whitefly adults trapped in the monocropped bean treatments. It is possible that fewer whitefly adults entered the corn treatments than the monocropped bean, but that a higher proportion of those entering the corn treatments were trapped. However, these considerations do not alter the overall impression that where air currents can enter, whitefly adults can follow.

Conclusion

Eggplant, transplanted a few weeks before bean was planted, did not serve as a trap crop for *B. argentifolii*. Wind direction was the overwhelming factor determining movement of whitefly adults into experimental plots with or without barrier crops. In downwind plots, corn rows planted perpendicular to the predominant wind direction

marginally reduced penetration of whitefly adults into plots on some dates when compared to bean monoculture and corn rows planted parallel to the wind. Corn barriers planted perpendicular to the wind may be useful at certain whitefly population densities when used with other control tactics.

Table 3-1. Mean (±SD) number of immature *B. argentifolii*/cm^2 on bean, 1996.

Wk	Treatment	Egg	Nymph	Para. Nymph[2]	REN[3]
1	Bean	0.79±0.58	0	0	0
	Corn	1.04±0.73	0	0	0
	Eggplant	1.27±0.68	0	0	0
	$\bar{x}$	1.03±0.67	0	0	0
3	Bean	0.62±0.40	0.64±0.29	0	0
	Corn	0.93±0.26	0.86±0.33	0.002±0.004	0
	Eggplant	1.00±0.58	1.31±0.87	0.006±0.01	0.004±0.008
	$\bar{x}$	0.85±0.44	0.94±0.59	0.003±0.008	0.001±0.005
4	Bean	0.40±0.30	0.79±0.30	0.010±0.008	0.010±0.02a
	Corn	0.67±0.49	1.10±0.65	0.010±0.004	0.002±0.004b
	Eggplant	0.60±0.27	0.80±0.25	0.004±0.005	0b
	$\bar{x}$	0.56±0.36	0.90±0.43	0.010±0.008	0.004±0.013
5	Bean	0.36±0.20	0.48±0.30	0.006±0.005	0.006±0.005
	Corn	0.39±0.10	0.80±0.51	0.016±0.015	0.008±0.013
	Eggplant	0.44±0.15	0.61±0.33	0.006±0.008	0.004±0.005
	$\bar{x}$	0.40±0.14	0.63±0.39	0.009±0.010	0.006±0.008
6	Bean	0.41±0.34	0.46±0.23	0.004±0.005a@	0.012±0.011
	Corn	0.43±0.16	0.58±0.22	0.020±0.015b	0.018±0.016
	Eggplant	0.46±0.14	0.67±0.26	0.010±0.007ab	0.016±0.011
	$\bar{x}$	0.43±0.22	0.57±0.24	0.011±0.012	0.015±0.012
7	Bean	0.54±0.58a[1]	0.51±0.26	0.010±0.01 a	0.010±0.010
	Corn	0.22±0.18b	0.44±0.15	0.016±0.015a	0.016±0.013
	Eggplant	0.34±0.32b	0.41±0.22	0.036±0.027b	0.014±0.008
	$\bar{x}$	0.37±0.39	0.46±0.20	0.021±0.021	0.013±0.010
8	Bean	0.26±0.16a	0.45±0.35	0.046±0.049	0.006±0.008
	Corn	0.06±0.04b	0.31±0.20	0.052±0.043	0.008±0.008
	Eggplant	0.11±0.16b	0.33±0.24	0.024±0.018	0.002±0.004
	$\bar{x}$	0.14±0.15	0.36±0.26	0.041±0.038	0.005±0.007

[1]Means assigned different letters in the same column and week of sampling are significantly different according to Tukey's Studentized Range test with an adjusted experiment-wise error rate of α=0.05. @ indicates α=0.1. [2]Parasitized nymphs. [3]Red-eyed nymphs (pharate adults).

Table 3-2. Immature *B. argentifolii* (mean ± SD/cm^2) on bean and eggplant, 1996.

	Egg		Nymph		Parasitized nymph		Red-eyed nymph	
Date	Bean	Eggplant	Bean	Eggplant	Bean	Eggplant	Bean	Eggplant
Aug. 25		0.66±0.46		0		0		0
Sept. 1		0.89±1.02		1.31±1.60		0		0
Sept. 8		1.03±0.65		0.52±0.33		0		0.003±0.006
Sept.16		3.53±0.72		2.39±0.33		0		0.007±0.006
Sept.22	1.66±1.67@	2.74±1.72@	0*	1.84±1.72*	0	0	0	0
Sept.29	5.52±3.44*	1.68±1.72*	0.88±0.62*	2.13±1.78*	0	0	0@	0.031±0.104@
Oct. 8	0.65±0.31*	0.24±0.41*	1.59±0.83*	0.29±0.19*	0.005±0.016*	0.035±0.037*	0.005±0.016	0.012±0.015
Oct. 21	0.64±0.54*	0.23±0.22*	0.45±0.35	0.49±0.65	0.009±0.014	0.025±0.038	0.003±0.009	0.046±0.078
Nov. 4	0.26±0.26*	0.02±0.03*	0.28±0.19*	0.11±0.10*	0.024±0.043@	0.069±0.067@	0.006±0.012*	0.048±0.043*

*indicates that numbers on bean and eggplant are significantly different on a given date according to analysis of variance at α=0.05.
@ indicates α=0.1.

Table 3-3. Analysis of variance for whitefly release data, 1997

		August 8	August 9	August 24	August 25
Source	df	F	F	F	F
Block	3	10.74**	32.76**	56.24**	12.34**
Treatment	2	0.02	0.86	1.78	2.01
Trap position	4	4.67*	4.65*	2.99@	2.86@
Block*treatment	6	4.10**	2.54*	5.28**	1.81
Block*trap position	12	1.48	1.23	7.84**	0.80
Treatment*trap position	8	0.59	0.94	0.13	1.77

**$p < 0.01$; *$p < 0.05$; @ $p < 0.1$.

Table 3-4. Whitefly adults (mean ± SD) per trap under 3 cropping systems, August 1997.

		Bean Alone		Corn: Barrier to Wind		Corn: Open to Wind	
Date	Row	Downwind	Upwind	Downwind	Upwind	Downwind	Upwind
Release 1[1]							
Aug. 8	1	1.67±2.25	0.33±0.52	2.33±1.03	0.33±0.52	2.33±1.21	0.50±0.84
	2	1.33±1.97	0	1.00±0.63	0	0.33±0.52	0.17±0.41
	3	0.67±0.52	0	1.33±1.51	0	0.17±0.41	0.17±0.41
	4	0.50±0.55	0.33±0.52	0.33±0.52	0	0.67±0.82	0
	5	0.33±0.52	0	0.17±0.41	0.16±0.41	0.67±1.03	0
	$\bar{x}$[3]	0.90±1.40*	0.13±0.35*	1.03±1.16*	0.10±0.31*	0.83±1.12*	0.17±0.46*
Aug. 9	1	2.00±1.79	0.17±0.41	1.17±0.75	0	1.83±1.47	0.33±0.52
	2	1.67±0.82	0.33±0.52	1.00±0.89	0.17±0.41	1.17±1.17	0
	3	1.50±1.22	0	0.83±0.98	0	0.67±1.21	0
	4	0.50±0.55	0	0.50±0.84	0	1.00±0.89	0
	5	0.50±0.84	0.17±0.41	0.67±0.82	0	0.50±0.84	0
	$\bar{x}$	1.23±1.22*a[2]	0.13±0.35*	0.83±0.83*b	0.03±0.18*	1.03±1.16*ab	0.07±0.25*
Release 2[1]							
Aug. 24	1	3.00±2.00	0.33±0.52	2.83±3.25	0	3.50±2.17	0.17±0.41
	2	1.67±1.21	0.17±0.41	1.50±1.05	0.17±0.41	2.50±1.05	0.17±0.41
	3	0.83±0.75	0.17±0.41	0.50±0.84	0	1.83±1.33	0
	4	0.50±0.55	0.17±0.41	0.17±0.41	0	1.17±0.41	0
	5	0.33±0.52	0.17±0.41	0	0	1.33±1.21	0
	$\bar{x}$	1.27±1.46*b	0.20±0.41*	1.00±1.82*b	0.03±0.18*	2.10±1.52*a	0.07±0.25*

Aug. 25	1	3.33±1.97	0.17±0.41	0.33±0.52	0	1.17±1.17	0
	2	1.00±1.10	0	1.00±1.10	0	1.00±0.89	0
	3	1.17±0.98	0	0.17±0.41	0	0.50±0.55	0
	4	0.67±0.82	0	0.33±0.82	0	0.83±1.17	0
	5	0.33±0.52	0	0.17±0.41	0	1.00±0.89	0
	$\bar{x}$	1.30±1.53*a	0.03±0.18*	0.40±0.72b@	0	0.90±0.92*a@	0*

[1]Wind direction on release dates: Aug.8: 75°; Aug.9: 97°; Aug. 24: 61°; Aug. 25: 55°.

*indicates mean trap counts in the same treatment upwind and downwind of the release point are significantly different at $p < 0.05$ according to F-test for contrasts.

[2]Different letters indicate that mean trap counts in blocks downwind of release point are significantly different at $p < 0.05$ according to F-test for contrasts.

@ indicates means are significantly different at $p < 0.1$ according to F-test for contrasts.

[3]Row refers to trap location (1=nearest, 5- farthest from release point; see text). $\bar{x}$ = mean across all 5 row locations.

CHAPTER 4

THE ROLE OF CROP DIVERSITY IN THE MANAGEMENT OF A WHITEFLY (HOMOPTERA: ALEYRODIDAE) SPECIES COMPLEX ON BEAN (*PHASEOLUS VULGARIS* L.) AND TOMATO (*LYCOPERSICON ESCULENTUM* MILL.) IN THE SALAMÁ VALLEY, BAJA VERAPAZ, GUATEMALA

Introduction

Intercropping is the agronomic practice of growing two or more crops in a field at the same time (Andrews and Kassam 1976). Intercrop arrangements include growing crops in alternating rows (row intercropping), mixing crops within a row or without regard to rows (mixed intercropping), and relay intercropping, which allows partial overlap of crop cycles (Andrews and Kassam 1976). Among the advantages attributed to some intercropping systems is reduced pest damage (Kass 1978, Litsinger and Moody 1976, Perrin 1977). Reviews of the intercropping literature indicate that, relative to monoculture, herbivore numbers were lower in more than 50 percent of the intercropping systems studied, greater in 15 to 18 percent of the cases, and variable in about 20 percent of studies (Andow 1991a, Risch et al. 1983).

Several theories have been proposed to explain how intercropping may reduce pest damage (Altieri 1994, Andow 1991a,Vandermeer 1989). Pimentel (1961) articulated the idea that diverse cropping systems will support arthropod communities which are more diverse and comprised of populations which are less dense and more stable than arthropod communities in monocultures. It was hypothesized that natural enemies might be more efficient in diverse agroecosystems than in simple ones, and that by damping

oscillations in arthropod populations, crop diversity would reduce pest outbreaks (Elton 1927, 1958, Pimentel 1961). This "enemies" hypothesis was summarized by Root (1973), who added to it the "resource concentration" hypothesis to explain reduced herbivore damage in some complex agroecosystems. The "resource concentration" hypothesis suggests that exploitation of crops by specialist herbivores can be reduced by breaking up monocultures. Damage by polyphagous herbivores may also be reduced by the presence of poor or non-hosts in mixed systems by the "flypaper effect" (Trenbath 1976, 1977). Finally, trap crops can be used in intercropping to draw herbivores away from a main crop (Vandermeer 1989).

The theory that diversity in itself will reduce pest damage has been largely discarded as inconsistent with empirical data (Andow 1991a, Risch et al 1983). More recent analysis suggests that the interaction between a cropping system and its arthropod community is determined largely by the specific characteristics of each (Andow 1991a, Kareiva 1983, Sheehan 1986, Stanton 1983). The ratio of host to non-host species will have a greater effect on herbivore abundance than the actual number of crop species (Power 1990, Stanton 1983). The response of both herbivores and natural enemies to a given cropping system will depend on their host range, their host-finding mechanisms, and their mobility (Kareiva 1983, Power 1990, Russell 1989, Sheehan 1986, Stanton 1983).

Many small farmer cropping systems in the tropics rely on the principles of intercropping to produce a range of goods for the home and market (Altieri and Hecht 1990, Kass 1978). Efforts by low resource farmers to improve income by concentrating

on higher-value market and export crops have resulted in an increase in pesticide use and pesticide-related health problems in Central America (Murray 1991, Nicholls and Altieri 1997). In Guatemala, the cultivation of non-traditional export crops has been associated with reduced nutrition (Barrett 1995) and increased debt in some communities (Glover and Kuterer 1990, Rosset 1991). The present series of studies was undertaken with the intention of developing an intercropping system which helped meet the economic and nutritional needs of low resource farmers by including both subsistence crops (bean, *Phaseolus vulgaris* L.; and corn, *Zea mays* L.) and a market crop (tomato, *Lycopersicon esculentum* Mill.) while reducing pesticide use.

Whiteflies cause economic damage to agronomic and horticultural crops throughout the tropics (Brown et al. 1995, Byrne et al. 1990, Byrne and Bellows 1991). *Trialeurodes vaporariorum* (Westwood), the greenhouse whitefly, *Bemisia tabaci* (Gennadius), the sweetpotato whitefly, and *Bemisia argentifolii* Bellows and Perring (also known as *B. tabaci* strain B), the silverleaf whitefly, are among the most damaging species on annual crops. These three whitefly taxa reduce yields by vectoring viruses, inflicting plant disorders, and causing mechanical damage to members of most crop groups except the grasses (Byrne et al. 1990). Whiteflies have developed some degree of resistance to most classes of pesticides (Denholm et al. 1996, Dittrich et al. 1990), forcing growers and researchers to evaluate alternative methods of control. Imidacloprid (Bayer) is a systemic insecticide which is currently effective against whiteflies and other sucking insects (Polston et al. 1994). Detergents and oils have been used successfully to manage whiteflies under certain conditions (Stansly 1995).

Attempts to manage whiteflies with intercropping have produced variable results. Al Musa (1982) and Schuster et al. (1996) reduced *Bemisia*-vectored geminivirus on tomato by trap cropping with cucumber (*Cucmis sativus* L.) and squash (*Cucurbita pepo* L.), respectively. However, efforts to reduce whitefly densities with trap crops have generally been unsuccessful (Ellsworth et al. 1994, McAuslane et al. 1995, Puri 1996). Barrier crops have been used to reduce densities of *Bemisia* (Morales et al. 1993) and incidence of whitefly-transmitted virus on cowpea (*Vigna unguiculata* (L.) Walp.) (Sharma and Varma 1984) and soybean (*Glycine max* (L.) Merrill) (Rataul et al. 1989). Gold et al. (1990) found that densities of immature cassava whiteflies *Aleurotrachelus socialis* Bondar and *Trialeurodes variabilis* (Quaintaince) were lower on cassava (*Manihot esculenta* Crantz) intercropped with cowpea than on monocropped cassava, but attributed this in part to reduced host quality in intercropped treatments. Ahohuendo and Sarkar (1995) reduced density of *B. tabaci* and incidence of cassava virus on cassava by intercropping with maize (*Zea mays* L.) and cowpea. Fargette and Farquet (1988) found that densities of *B. tabaci* and virus incidence were sometimes higher on cassava intercropped with maize than on cassava grown alone.

The origin of the whitefly problem in Central America is associated with the dense populations that developed on large-scale cotton (*Gossypium hirsutum* L.) plantations along the region's Pacific coastal plain in the 1960s (Dardón 1992). Bean golden mosaic geminivirus, vectored by *B. tabaci* (Costa 1975), was first described in Guatemala in 1963 (Scheiber 1983). After peaking in the late 1970s, bean golden mosaic declined in importance until 1989, when it decimated bean crops throughout Central America (Rodriquez 1994). Devastating whitefly-transmitted geminiviruses spread

throughout tomato-producing areas of Central America and the Caribbean during the late 1980s (Brown 1994), severely impacting Guatemala in 1987 (Dardón 1992). This explosion of tomato geminiviruses is attributed to the arrival of the 'B' strain of *B. tabaci*, also known as *B. argentifolii*, throughout the region (Polston and Anderson 1997).

Whitefly problems in Central America tend to be attributed to *Bemisia*, but there are at least 15 genera of whiteflies in the region with varying degrees of economic importance (Caballero 1994). According to Caballero (1994), *Trialeurodes vaporariorum* tends to be found in areas more than 1000 m above sea level, whereas *B. tabaci* is rarely found above 1000 m. *Trialeurodes vaporariorum* does not vector geminiviruses (Brown and Bird 1992), but its importance relative to *Bemisia* at higher elevations may be underestimated.

The following experiments were a component of a broader effort to evaluate the potential of intercropping for management of whiteflies. Prior field studies at the University of Florida in Gainesville, Florida, indicated that trap cropping with squash or eggplant (*Solanum melongena* L.) was ineffective in reducing densities of *B. argentifolii*, and that using corn as a barrier crop was only marginally effective (see Chapters 2 and 3). After consulting with pest management specialists from the Guatemala, San Jerónimo was chosen as a suitable site in which to test intercropping and whitefly management in the context of small farmer cropping systems. San Jerónimo is at the eastern end of the Salamá valley, a major tomato-producing area in central Guatemala. A system of gravity-fed irrigation canals was built in this portion of the valley in the mid-1970s, permitting year-round cultivation of tomato and other crops. This has improved the local economy,

but may have contributed to the unmitigated build-up of whitefly populations in the area since the 1980s.

The current study was undertaken to determine if whitefly numbers on bean and tomato could be reduced by intercropping with crops that were either poor hosts or non-hosts for whitefly. Pesticide treatments were included in some studies to determine if intercropping combined with pesticide application offered any advantage over either control measure alone. The last study included a comparison of mechanical and chemical methods of whitefly protection for tomato in the nursery stage, prior to transplanting into monocropped and intercropped environments.

Materials and Methods

Location

This series of experiments was carried out at the Instituto de Ciencia y Tecnología Agrícolas (ICTA) field station in San Jerónimo (15° 03' 40" N, 90° 15'00" W), Baja Verapaz, Guatemala. ICTA is the government agricultural research institute of Guatemala. The station is 1000 m above sea level. The area is classified as subtropical dry forest under the Holdridge system (Holdridge 1967, de la Cruz 1982). The dry season is from November to April. The soils on the station belong to the Salamá series and are characterized as loose and friable, with a low cation exchange capacity and a substratum of volcanic ash (Krug 1993, Sharer and Sedat 1987).

Overview

Three sets of experiments were carried out between March and December 1998 to evaluate the effect of three distinct intercropping arrangements on the densities of immature whiteflies on bean and tomato. Numbers of whitefly eggs and nymphs on

intercropped plants were compared with numbers on monocropped plants for each study. These studies are referred to as the diversity, mosaic, and corn/cilantro studies. The corn/cilantro study included a comparison of two methods of tomato production in the nursery.

Diversity Study

This study was initiated in March toward the end of the dry season, when whitefly populations are at their highest. Bean or tomato was intercropped in alternating rows with corn, cabbage (*Brassica oleracea* L.), cilantro (*Coriandrum sativum* L.), rosa de jamaica (*Hibiscus sabdariffa* L.), and velvetbean (*Mucuna deeringiana* (Bort.) Small) (Figure 4-1). These crops are either poor or non-hosts for whiteflies, and were chosen from crops grown regionally to represent a diverse range of plant architecture and plant chemistry. All have dietary and market value, except for velvetbean, which is primarily used as a forage and green manure. The purpose of the study was to determine if the presence of varied poor and non-hosts affected whitefly densities on bean and tomato when compared to densities on bean and tomato grown in monoculture. This study included subplots with pesticide treatments.

After the first bean crop had been harvested, a second bean crop was planted on smaller scale. Whitefly numbers on monocropped and intercropped bean were compared without pesticide subplot treatments.

The bean variety used was 'ICTA-Santa Gertudis,' a cultivar developed and promoted by ICTA as resistant to bean golden mosaic. 'Elios' tomato seedlings (Petoseed, Saticoy, CA) were purchased from Saúl Vasquez, Estancia La Virgen, El Progreso. The field corn hybrid used was 'ICTA HB-83' (ICTA 1993). 'Costanza'

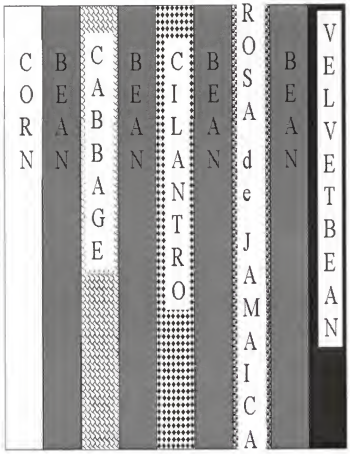

Figure 4-1. Intercrop Pattern: Diversity Experiment

cabbage (Petoseed, Saticoy, CA) was used. Cultivar information was not available for cilantro, velvet bean, and rosa de jamaica, which were grown from locally-acquired seed.

A tractor was used to cultivate the experimental area and form rows at the beginning of the dry season (March 19) and rainy season (August 13) experiments. Application of fertilizer, weeding and all other aspects of plot management were carried out manually. Crops were fertilized according to local recommendations (ICTA 1993, Superb 1997). Fungicides and pesticides were applied with a 16-liter Matabi "Super 16" backpack sprayer (Goizper S. Coop., Guipuzcoa, Spain). Fungicides were applied on a weekly basis to tomato to control for foliar and root pathogens once the rains began in May. Water from a furrow irrigation system was made available to the station every 6 days for 3 days during the dry season and upon request during the rainy season.

A split plot design was used with 2 whole plot treatments (monocrop, intercrop) and 3 subplot pesticide treatments (imidacloprid, detergent/oil, control). Each treatment was replicated 4 times.

Whole plots contained 17 rows, 17 m in length. Monocrop plots consisted of 8 rows of bean and 8 rows of tomato separated by one bare row. Intercrop plots consisted of 8 rows of a bean/intercrop mix next to 8 rows of tomato/intercrop mix. A row of velvetbean separated the bean and tomato sections in the intercrop plots. The other 4 intercrop species were planted in alternating rows with bean or tomato to either side of the velvetbean in the following order: rosa de jamaica, cilantro, cabbage, corn.

Spacing between plants was 20 cm for bean, corn, cilantro, and velvetbean and 40 cm for tomato and cabbage. Space between rows was 1.0 m. Rows were planted north to south. Corn, cabbage, cilantro and rosa de jamaica were planted 25 March. Velvetbean

was planted 26 March. Beans were planted 5 and 6 April. Tomatoes in the untreated and detergent/oil plots were transplanted 6 May.

Each whole plot was divided into 3 sections of 5.67 m in length. These sections were demarcated with nylon cord supported by stakes. Each section was randomly assigned to the imidacloprid treatment, the detergent and oil treatment, or the control.

Imidacloprid (Confidor 70 WG) was prepared at a rate of 0.73 g/liter of water. Approximately 10 cc of this mixture (73 mg imidacloprid) was applied to the base of each plant at each application. Imidacloprid was applied to bean at emergence, 1 week after emergence and 3 weeks after emergence. Imidacloprid is not registered for bean, and was included for comparison only. Commercially-produced tomato seedlings received 1 imidacloprid application in the nursery, and were treated 1 and 3 weeks after transplanting.

Olmeca® vegetable oil (Olmeca S.A., Guatemala) and Unox® laundry detergent (Quimicas Lasser S.A., El Salvador) were applied at a rate of 1% , or 16 cc/16 liter spray tank (Calderón et al. 1993). An elbowed nozzle attachment was used to apply the mixture to the lower surface of leaves. Detergent or oil was applied in rotation every 5 days.

Whitefly Identification

Plants were examined under a dissecting microscope and the numbers of whitefly eggs, nymphs, parasitized nymphs, and fourth-instar nymphs were recorded. The eyes of the pharate adult become apparent in the final stage of fourth-instar *Bemisia* nymphs. This stage was used to estimate the proportion of *Bemisia* relative to *T. vaporariorum* in the nymph population. Earlier instars of *Bemisia* and *T. vaporariorum* can be

distinguished, but this is prohibitively time-consuming when high numbers of nymphs are being counted.

In each study and for all crops, only the underside of leaves was examined for whitefly immatures (Ekbom and Rumei 1990).

Bean was sampled on 6 occasions: 17 April (1 week after emergence), 25 April, 3 May, 12 May, 19 May, and 17 June. The sample unit on weeks 1 through 3 and week 5 was a 3.35 cm^2 disc removed with a cork borer from upper and lower leaves (McAuslane et al. 1995). The disc was removed from the underside of the central leaflet to the right of the mid-vein. Five plants per plot were sampled on these weeks. The average of the 2 discs was used in treatment analysis. On weeks 4 and 6, one whole plant per subplot replicate was sampled. Five plant heights per plot were measured on weeks 3, 5, and 6. Five plants per plot were weighed on weeks 4, 5, and 6.

During week 4, five whole bean plants per plot were enclosed quickly in plastic bags and refrigerated. These plants were sampled to estimate the number of generalist predators on the bean plants as well as whitefly immatures.

Tomato was sampled on 4 occasions: 19 May, 1 June, 28 June, and 17 July. Disc samples were taken from upper and lower strata on the first 2 sample dates. Whole branches were examined for whitefly immatures from upper, middle and lower plant strata on the latter two dates. Whole plants and branches were weighed to estimate the percentage of the whole plant represented by the 3 strata. Five plants per plot were sampled on the first two sampling dates, and one plant per plot was sampled during the second two dates. Height and weight data on five plants per plot were gathered on weeks 2 and 3.

Fourth-instar whitefly nymphs were mounted in the laboratory of Lic. Margarita Palmieri at the Universidad del Valle in Guatemala City and sent to Dr. Avas Hamon of the Division of Plant Industry for identification. Dr. Andrew Jensen of the United States Department of Agriculture in Beltsville, MD, kindly identified nymphs on dried plant material. Leaves or whole plants with nymphs showing symptoms of parasitism were placed in unwaxed cylindrical 0.95-liter cardboard cartons (Fonda Group Inc., Union, NJ, USA) for parasitoid emergence. Several weeks later, dead parasitoids were placed on cotton in gel capsules and sent to Dr. Greg Evans of the Division of Plant Industry, Gainesville, FL, for identification.

Tissue from bean and tomato plants exhibiting symptoms of bean golden mosaic or tomato leaf curl was analyzed using ELISA (Agdia Inc., Elkhart, IN) in the laboratory of Lic. Margarita Palmieri. The total number of plants per row and number of plants with bean golden mosaic symptoms was counted for all even-numbered rows in each bean study. The total number of plants per row was counted in even-numbered rows for the tomato treatments. Attempts to estimate percentage tomato leaf curl visually were abandoned because virus symptoms are easily confused with other tomato disorders (Polston and Anderson 1997).

Five velvetbean plants were examined for whitefly immatures on 3 May and 9 May. The leaves were traced onto paper, and this area was measured using a LI-COR portable leaf area meter (model LI-3000A, LI-COR Inc., Lincoln, NE) in the United States. Whole plant examinations were made of 12 cabbages on 6 June and 10 rosa de jamaica plants on 8 June.

Imidacloprid-treated bean was harvested 29 June. Detergent/oil bean and untreated bean was harvested 6 July. Tomato was harvested each week from 15 July through 12 August and classified as large, medium, small, and reject.

On 10 July a second bean crop was planted in the former imidacloprid subplots. A randomized complete block design with 4 replications was used to compare whitefly immatures on bean grown under 2 treatments: monocropped and intercropped with the five mature and senescing poor and non-host crops.

Spacing between bean plants was 20 cm. Bean was sampled weekly for 6 weeks from 19 July through 23 August. Eight whole bean plants per plot were sampled during week 1, four plants per plot on week 2, and two plants per plot for the remaining weeks. The number of trifoliate leaves per plant was recorded each week. Bean was harvested 20 September.

Statistical Analysis

Treatments were compared using analysis of variance for split plot or randomized complete block, followed by mean separation when appropriate (SAS Institute 1996).

Mosaic Experiment

This study was carried out toward the end of the rainy season. A mixed intercropping pattern was used to evaluate corn and rosa de jamaica as crops which might offer a cryptic environment for bean and tomato when intercropped in a mosaic pattern. The same crop cultivars were used as in the diversity experiment. Tomato seedlings were bought from Piloncito Verde, Chimaltenango.

Densities of immature whiteflies were compared on bean and tomato grown under two treatments: bean and tomato grown in monoculture, and bean and tomato

intercropped with corn and rosa de jamaica. Each treatment was replicated 4 times and arranged in a randomized complete block design. Monocrop plots contained 4 rows of tomato adjacent to 4 rows of bean. Intercrop plots consisted of 8 rows of mixed crops (Figure 4-2). The order of crop species within the row for the intercrop treatment was corn, rosa de jamaica, bean, corn, rosa de jamaica, tomato. The first crop in consecutive rows was staggered so that each bean or tomato plant was surrounded by corn, rosa de jamaica and the other main crop, but was not immediately adjacent to a conspecific.

Rows were 8 m in length and between row spacing was 1.0 m. Between plant spacing was 40 cm for all intercrop plants and the monocrop tomato, and 20 cm for monocrop bean. Corn and rosa de jamaica were planted 18 August. Bean was planted 8 October. Tomato seedlings were transplanted 20 October.

Whole plant counts were taken for bean each week from 18 October through 17 November. Six plants per plot were sampled during the first week, 4 plants per plot during weeks 2-4, and 2 plants per plot for the last 2 weeks. Plant height was measured each week. Number of branches was recorded during weeks 3-6, and plants were weighed in weeks 4-6. Number of plants per row and number of plants with bean golden mosaic symptoms was counted 2 December.

Whole plant counts were taken for tomato for 4 weeks from 21 October through 12 November. On 22 November and 4 December, only the lower third of the plant was sampled because the plants were too large for whole plant counts. During the first 2 weeks, 4 plants per plot were sampled. During week 2, two plants per plot were sampled. During the remaining 3 weeks, 3 plants per plot were sampled. Plant heights were measured during the first 5 weeks of sampling. Number of branches per plant was

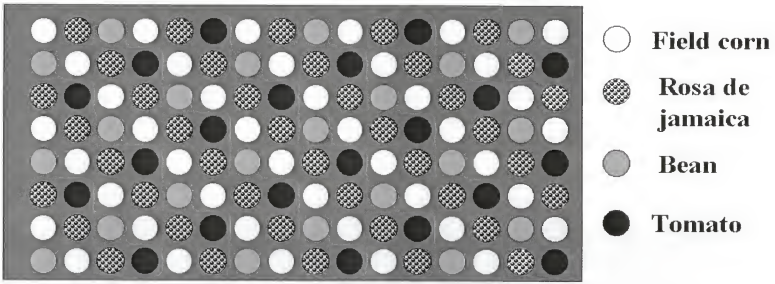

Figure 4-2. Intercrop Arrangement, Mosaic Experiment

recorded for weeks 2-5, and fresh plant weights were taken during weeks 3-5. On 2 December the number of tomato plants per row was recorded.

On 7 October one whole rosa de jamaica plant per block was examined for whitefly immatures.

Statistical Analysis

Numbers of whitefly immatures and plant size characteristics were compared between treatments using analysis of variance with SAS software (SAS 1996).

Nursery and Corn/Cilantro Study

In the final study, carried out toward the end of the rainy season, an attempt was made to develop an overall management program for whitefly on tomato. Two methods of tomato seedling production were compared in a nursery study. Seedlings were either treated with imidacloprid or grown under protective mesh in covered nurseries. The seedlings produced in this nursery study were then used in the corn/cilantro study. Tomatoes in the corn/cilantro study were grown under four treatments: monocropped with and without imidacloprid, and intercropped with and without imidacloprid. The seedlings used in the imidacloprid treatments were those which had been treated with imidacloprid in the nursery. The untreated seedlings were those which had been grown under protective mesh.

The intercrop treatment consisted of tomato intercropped with corn and cilantro. High numbers of generalist predators had been observed on flowering cilantro in the diversity study, and an attempt was made to increase densities of predators on tomato by intercropping with cilantro. In the intercrop treatment, corn was used to anchor the nylon cord which supports growing tomato, replacing the wooden stakes which are normally

employed for this purpose. Intercropping tomato with mature field corn is not uncommon among small farmers in Guatemala (Eduardo Landeverri, ICTA agronomist, personal communication). The corn was widely spaced, and specifically managed to reduce shading: lower leaves were removed from the corn early in November, and corn was harvested in the fresh ("elote") stage on 19 November, after which the top of the each corn plant was removed.

Nursery Study

Tomato plants used in this study were grown individually in containers made from newspaper ("cartuchos") on the research site (Rufino 1998). Seeds were planted in cartuchos on 21 September. About 300 seedlings were dusted with imidacloprid (Gaucho 70 WC; Bayer, Germany) before planting and grown in an exposed nursery. Another 300 seedlings were grown in a nursery protected from whiteflies by fine nylon mesh (Rivas et al. 1994) and received no pesticide treatment. The treated seedlings received approximately 73 mg imidacloprid (Confidor 70 WG) on 8 October. The height of eight tomatoes from each nursery treatment was measured on 18 October, when the nursery covering was removed. Eight plants from the two nursery treatments were examined for whitefly immatures on 18 October. Tomato seedlings were transplanted into the corn/cilantro study 19 October.

Corn/Cilantro Study

A randomized complete block split plot design was used with 2 wholeplot treatments (monocrop and intercrop) and 2 subplot treatments (imidacloprid treatment and control). The imidacloprid treatment consisted of tomato plants which received imidacloprid in the nursery study and in two post-transplant applications. The control

treatment was comprised of tomato seedlings produced under protective mesh in the nursery study which received no pesticide applications before or after transplanting.

Each treatment was replicated 4 times. Main treatment plots were 6 m^2. Each main treatment plot was divided in half with nylon cord to produce two subplots, each 6 x 3 m. Monocrop and intercrop whole plots were separated by a 6 m^2 patch of corn. Approximately 73 mg imidacloprid (Confidor 70 WG) was applied to tomatoes in the imidacloprid treatment on 22 October and 5 November.

Corn was planted 18 August and spaced every 2 m on the east side of the bed. Cilantro was planted in a nursery 20 August and transplanted into the intercrop plots 2 October. Cilantro was planted every 12 cm on the west side of the bed. Tomato was planted every 40 cm.

Tomato plants in the corn/cilantro study were sampled for 6 weeks, from 21 October through 2 December. Whole plant counts were made during weeks 1-4. During weeks 5 and 6, only the lower third of the plant was sampled because of plant size. Four plants per plot were sampled during weeks 1-3. Two plants per plot were sampled during week 4, and 3 plants per plot were sampled during weeks 5 and 6.
Number of branches per plant was recorded for weeks 1-5. Plant heights were recorded weeks 2-5, and weights were measured weeks 3-5.

On 5 November, two beat cloth samples per subplot were taken from tomato to estimate generalist predators. A 1.0 m x 0.75 cm plastic sheet was spread out on a wooden board at the base of two adjacent tomato plants. The plants were struck swiftly 4 times toward the sheet, which was then folded into a ball and sealed with masking tape.

The samples were first refrigerated, then transported to the Universidad del Valle in Guatemala City for identification.

Weather data was provided by the Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología, San Jerónimo station.

Statistical Analysis

Treatments were compared using analysis of variance for split plot or randomized complete block, followed by mean separation when appropriate (SAS Institute 1996).

Results and Discussion

The predominant whitefly species in the Salamá valley was determined to be *T. vaporariorum*. Whitefly populations were highest at the end of the dry season (March-May), dropped with the first cool, wet months of the rainy season (June-August), but rose again to high levels by the end of the rainy season (October-November). Relatively few fourth-instar *B. tabaci* nymphs were observed throughout the 10-month study. Observations of fourth-instar *B. tabaci* and geminivirus symptoms on bean and tomato were highest at the end of the dry season and rare at the end of the rainy season. In the middle of the rainy season, when overall whitefly populations were at their lowest, almost 50% of observed fourth-instar nymphs were *Bemisia*. The strain or strains of *B. tabaci* present in the Salamá valley were not determined.

Diversity Study

Differences in levels of whitefly immatures, predators, plant density, percent bean golden mosaic geminivirus and yield were not significant between monocropped and intercropped treatments on any sampling date ($p < 0.1$). Statistical differences in the diversity study occurred among subplot pesticide treatments only.

During week 1, egg counts were lower ($p < 0.05$) in the imidacloprid-treated intercrop than in the control intercrop (Table 4-1). During week 2, egg counts were lower ($p < 0.05$) in the imidacloprid and detergent/oil treatments than the control. Nymph counts during week 2 were different ($p < 0.05$) among all treatments, with the lowest counts in the imidacloprid treatment and the highest in the detergent/oil treatment.

Three weeks after germination, bean plants treated with imidacloprid were clearly larger and more robust than those in the detergent/oil treatment and control. Plants in the detergent/oil treatment showed symptoms of phytotoxicity. In addition, plants in the detergent/oil and control treatments were stunted, with shortened stems and petioles. A chlorotic burn appeared along the leaf border and tip, typical of leafhopper damage. Whole plant examinations during week 4 revealed high densities of thrips (Thysanoptera) and leafhoppers (Homoptera: Cicadellidae) on plants in the detergent/oil treatment and the control. Size differences between the imidacloprid-treated bean and the other two treatments increased during subsequent weeks.

The imidacloprid-treated plants tended to have more eggs and nymphs than the stunted plants in other treatments during weeks 3 and 4 (Table 4-2). There were no subplot treatment differences during weeks 5 and 6 as plants senesced and whitefly populations declined.

Fourth-instar *B. tabaci* nymphs were observed for the first time during whole plant examinations on week 4. Densities of fourth-instar *B. tabaci* were lower ($p < 0.10$) in the imidacloprid treatment (0.13 ± 0.35/plant) than in the control (7.62 ± 12.22). Densities in the detergent/oil treatment were intermediate (0.38 ± 0.52). The ratio of fourth-instar *Bemisia* to *Trialeurodes* from all treatments during week 4 was 65: 573.

Incidence of *Bemisia* during the following two weeks was not high enough for meaningful comparison.

Generalist predators collected from whole plant bean samples during week 4 included *Geocoris* sp. (Hemiptera: Lygaeidae), Coccinellidae (Coleoptera), Thysanoptera, Neuroptera, syrphid larvae (Diptera: Syrphidae), and spiders. Only *Geocoris* sp. was present in sufficient quantities for statistical comparison. Levels of *Geocoris* sp. were higher ($p < 0.001$) on imidacloprid-treated bean (0.60 ± 0.87/plant) than on bean in the detergent/oil treatment (0.05 ± 0.22) and the control (0.25 ± 0.16).

The parasitoids reared from bean and tomato in the diversity experiment were almost entirely *Encarsia pergandiella* Howard (Hymenoptera: Aphelinidae), although a few individuals from the *Encarsia meritoria* species complex were reared from the second bean crop early in August. Sex ratios for *E. pergandiella* ranged from a low of about 15% males in mid-May, when host and parasitoid populations were high, to 33% males in July and August, when overall populations were low, to about 26% males in November and December, when both populations were high again.

There were no statistical differences ($p < 0.1$) among treatments in levels of parasitized nymphs during week 4 (12.33 ± 16.79/plant). Parasitism was higher ($p < 0.05$) in the imidacloprid treatment than the other two treatments during week 5 (imidacloprid: $2.98 \pm 4.19/cm^2$, detergent/oil: 0.13 ± 0.34, control: 0.78 ± 1.26) and week 6 (imidacloprid: 29.50 ± 21.23/plant, detergent/oil: 6.00 ± 6.30, control: 4.75 ± 6.86). Percent parasitism, calculated as the percentage of parasitized nymphs to parasitized and fourth-instar nymphs combined, ranged from about 33% during week four to 80% during week 6. Parasitism and numbers of *Geocoris* were presumably highest on imidacloprid-

treated plants because these plants were larger and supported more hosts/prey than untreated plants.

There were more ($p < 0.05$) plants per row in the imidacloprid treatment (26.50 ± 4.88) than in the control (22.28 ± 6.75). Plant density in the detergent/oil treatment was intermediate (24.00 ± 7.76).

The percentage of plants with bean golden mosaic symptoms was different ($p < 0.05$) among all subplot treatments (imidacloprid: 7.27 ± 7.03 %; detergent/oil: 14.86 ± 10.53 %; control: 21.99 ± 15.86 %). Eight bean plants out of ten showing symptoms of bean golden mosaic tested positive for the presence of geminivirus.

The bean yield per row was higher ($p < 0.05$) in the imidacloprid treatment (0.29 ± 0.09 kg) than in the detergent/oil treatment (0.05 ± 0.03 kg) and the control (0.02 ± 0.03 kg), neither of which produced marketable yield.

Because of delays in planting, the imidacloprid treatment could not be included in the analysis. We learned when the tomato seedlings were delivered that all commercially-produced tomato seedlings are treated with imidacloprid in the nursery. Both detergent/oil and control seedlings received a pre-transplant imidacloprid treatment.

Whitefly populations on tomato remained low throughout the diversity study. This may be partially explained by the effect of imidacloprid and other chemicals applied in the nursery. In the third sample (June 28), there were more ($p < 0.05$) fourth-instar *T. vaporariorum* on the control (3.38 ± 3.07) than on the detergent/oil plants (0.71 ± 1.11). Observations of *Bemisia* were too few for analysis. There were no statistical differences ($p < 0.1$) among subplot treatments in density of whitefly immatures (Table 4-3),

parasitized nymphs (week 3: 6.53 ± 7.93/branch; week 4: 0.60 ± 0.91/branch), plants per row (11.16 ± 1.87), or total yield per row (5.69 ± 4.29 kg).

Seven tomato plants out of 10 showing geminivirus symptoms tested positive for the presence of geminivirus.

Very few whitefly eggs or nymphs were found on cabbage, rosa de jamaica and velvetbean. Cabbage plants were large (254.25 ± 180.88 g) with well-formed heads when sampled. Mean egg count was 0.17 ± 0.58/plant and mean nymph count was 3.25 ± 5.43. Two fourth-instar *T. vaporariorum* nymphs were found. Rosa de jamaica plants weighed 164.67 ± 150.92 g and were 49.33 ± 12.14 cm tall. No whitefly eggs were found on the rosa de jamaica. Average per plant count for nymphs and fourth-instar *B. tabaci* was 7.67 ± 6.89 and 0.89 ± 1.36 respectively. Velvetbean sampled on 3 May averaged 0.08 ± 0.06 eggs and 0.03 ± 0.04 nymphs/cm^2. Velvetbean sampled on 9 May averaged 0.01 ± 0.01 eggs and 0.05 ± 0.06 nymphs/cm^2.

Diversity Study: Second Bean Crop

Number of eggs was higher in the monocrop than the intercrop treatment during weeks 3 ($p < 0.05$) and 4 ($p < 0.01$) (Table 4-4). Egg numbers did not differ by treatment on other dates. However, intercrop plants had fewer trifoliates during week 5 ($p < 0.05$) and week 6 ($p < 0.01$). Overall egg and nymph densities were therefore higher on the intercrop plants during these weeks, since intercrop plants were smaller than monocrop plants. The smaller size of intercrop beans was probably due to shading from intercrops, particularly the rosa de jamaica, which was about 1.5 m tall in August.

There were no treatment differences ($p < 0.1$) on any sampling date for the second bean crop between numbers of nymphs (Table 4-4), parasitized nymphs (week 4: 0.25 ±

0.77/plant, week 5: 1.75 ± 2.89, week 6: 6.12 ± 8.61), or fourth-instar *T. vaporariorum* (week 4: 0.44 ± 0.81, week 5: 0.94 ± 1.12, week 6: 4.38 ± 7.82). There were no statistical differences ($p < 0.1$) between treatments in the numbers of fourth-instar *B. tabaci* during week 4 (0.37 ± 0.81) or week 6 (0.37 ± 0.81). The number of fourth-instar *B. tabaci* was lower ($p < 0.05$) in the monocrop treatment (0.50 ± 0.53) than in the intercrop treatment (1.13 ± 0.99) during week 5.

During weeks 4 and 5, *B. tabaci* made up 46% of the observed fourth-instar whitefly immatures (ratio of *B. tabaci* to *T. vaporariorum* was 6: 7 on week 4 and 13: 15 on week 5). On week 6, *B. tabaci* comprised 7% of the observed fourth-instar whitefly immatures (1: 15).

There were fewer ($p < 0.001$) plants per row in the intercrop treatment (60.13 ± 22.53) than in the monocrop treatment (82.19 ± 9.16). Yield per row was higher ($p < 0.05$) in the monocrop treatment (2.47 ± 0.53 kg) than in the intercrop treatment (1.25 ± 0.39 kg). The reason for the lower number of plants per row in the intercrop treatments is not clear. Possibly the weeding and fertilizing of the bean plants was impeded by the presence of intercrop plants, leading to reduced survival.

Leafhoppers and thrips were barely discernable on this second bean crop, although high populations of these insects decimated unprotected bean in the dry season. However, dense populations of chrysomelids (Coleoptera), primarily *Cerotoma* and *Diabrotica* spp., attacked the second bean crop early. *Cerotoma* and *Diabrotica* spp. are among the vectors of severe mosaic of bean, a comovirus (Morales and Cardona 1998). Dr. Francisco Morales of International Center for Tropical Agriculture, Cali, Colombia, identified symptoms of severe mosaic of bean among experimental plants in the field.

Leaf beetles typically build up on field corn, then move on to young beans as the corn senesces in the first months of the rainy season. Incidence of the virus was high among experimental plants. Leaf necrosis and deformation from severe mosaic of bean masked symptoms of bean golden mosaic, preventing an estimate of presence of bean golden mosaic at the end of the season.

Mosaic Study

Egg counts were lower ($p < 0.05$) on intercropped than monocropped bean during the first four weeks of sampling (Table 4-5). Nymph counts were lower ($p < 0.05$) on intercropped than monocropped bean on weeks 2, 4, and 5.

Lower numbers of eggs and nymphs among intercrop bean early in the study may be attributed to the emergence of intercrop plants into a cryptic environment. However, bean size and health were affected by shading from corn and rosa de jamaica soon after emergence, and the overall plant area available for colonization was presumably less than in the monocrop treatment by week 3. From weeks 3-6, intercrop bean was stunted compared to monocrop bean, and whitefly densities were correspondingly lower.

A few *Encarsia pergandiella* individuals and one member of the *Encarsia meritoria* species complex were reared from bean in the mosaic experiment. There were no treatment differences among numbers of parasitized nymphs (week 4: 0.88 ± 2.03/plant, week 5: 0.88 ± 2.03, week 6: 1.44 ± 2.66), fourth-instar *T. vaporariorum* (week 4: 0.13 ± 0.71, week 5: 0.88 ± 1.71, week 6: 4.19 ± 5.76), or fourth-instar *B. tabaci* (week 5: 0.06 ± 0.25, week 6: 0.06 ± 0.25). During week 5, *B. tabaci* fourth-instars comprised 7% of fourth-instar nymphs on bean. During week six, 1.5% of fourth-instar nymphs on bean were *B. tabaci*. Number of plants per row averaged 5.15 ± 2.49 in the

intercrop treatment, and 56.31 ± 5.88 in the monocrop treatment. Only two bean plants in the mosaic study showed symptoms of bean golden mosaic, both in the monocrop treatment.

There were no treatment differences in egg density on any sampling date (Table 4-6). Intercrop tomato was taller than monocrop tomato during weeks 2-4, resulting in higher numbers of whitefly nymphs on intercrop tomato during those weeks (Table 4-6). There were no treatment differences ($p < 0.1$) in numbers of fourth-instar *T. vaporariorum* during week 5 (36.33 ± 48.15/plant) or week 6 (48.92 ± 71.19). Numbers of parasitized nymphs (19.67 ± 18.76/plant) were not different ($p < 0.1$) between treatments during week 5. Numbers of parasitized nymphs were higher ($p < 0.1$) on intercrop tomato (50.67 ± 46.80) than monocrop tomato (23.00 ± 26.01) during week 6. Only one fourth-instar *B. tabaci* was found on tomato, comprising 0.08% of fourth-instar nymphs observed during week 6.

Parasitoids reared from tomato in the mosaic experiment consisted of *Encarsia pergandiella*, members of the *Encarsia meritoria* species complex, and *Amitus fuscipennis* MacGown and Nebeker (Hymenoptera: Platygasteridae) (Table 4-7). A Shannon-Weaver diversity index (H') (Shannon and Weaver 1949) of 0.383 was calculated for the parasitoid complex collected from tomato grown in monoculture, and an index of 0.996 was calculated for parasitoids reared from tomato mixed with corn and rosa de jamaica. We speculate that the presence of extra-floral nectaries on rosa de jamica favored the increased presence of the *E. meritoria* species complex and *A. fuscipennis*.

Unlike bean, which emerged into the shaded intercrop environment, tomato seedlings were produced under the optimal conditions of a commercial nursery. Tomato size was not affected by intercrop shading until 5 weeks after being transplanted (Table 4-6).

The mean number of tomato plants per row was 1.72 ± 0.85 for intercrop treatments and 15.25 ± 2.32 for monocrop treatments at the end of the study. The low number among the intercrop treatment is due to whole plant sampling of an initially small population.

As observed in the dry season, rosa de jamaica was a poor whitefly host. The mean weight and height of the 4 rosa de jamaica plants examined on 4 October was 150.75 ± 57.04 g and 70.75 ± 4.35 cm, and average leaf number was 68.75 ± 36.59. The average number of eggs and nymphs per plant was 5.50 ± 5.80 and 3.25 ± 1.50 respectively. One fourth-instar *B. tabaci* was found.

Nursery Study

Seedlings produced in covered nurseries were taller ($p < 0.1$) than imidacloprid-treated seedlings (19.94 ± 4.85 cm vs. 15.31 ± 4.99 cm) due to increased shade under mesh. The number of eggs per plant was not different ($p < 0.1$) between the covered nursery (0) and the imidacloprid-treated seedlings (0.13 ± 0.35).

Corn/Cilantro Study

Unseasonably high precipitation resulted in a high incidence of disease among both cilantro and tomato. Few cilantro plants per row reached the flowering stage. The 'corn/cilantro' study therefore became a study comparing monocropped tomato with tomato intercropped with corn, with and without imidacloprid.

Seedlings produced under mesh received heavy whitefly pressure as soon as they were removed from the covered nursery. This led to stunting of untreated seedlings. Imidacloprid-treated tomato was taller and heavier ($p < 0.05$) than untreated seedlings 3 weeks after transplanting (Table 4-8).

Egg numbers were lower ($p < 0.01$) in the imidacloprid treatment during weeks 1 and 6, and in the intercrop imidacloprid treatment during week 2 (Table 4-9). Egg numbers were lower ($p < 0.1$) in the monocrop than in the intercrop treatments during week 2. Nymph numbers were lower ($p < 0.05$) on the imidacloprid-treated intercrop plants during each week of sampling. Nymph numbers were lower ($p < 0.01$) on imidacloprid-treated plants in both cropping systems during week 3. During week 4, nymph densities were higher ($p < 0.05$) on the imidacloprid-treated tomato than on untreated tomato in the monocrop treatment. This was because imidacloprid-treated plants were considerably larger.

Parasitoids reared from tomato consisted of *Encarsia pergandiella*, members of the *Encarsia meritoria* species complex, and *Amitus fuscipennis* (Table 4-10). The overall parasitoid diversity in this experiment was low. Diversity indices (H') for parasitoid complexes reared from the four treatments were: monocrop plus imidacloprid: 0.113; monocrop untreated: 0.026; intercrop plus imidacloprid: 0.313; intercrop untreated: 0.176.

Densities of parasitized nymphs were higher ($p < 0.01$) in the untreated subplots (15.65 ± 14.79/plant) than the imidacloprid-treated subplots (1.38 ± 2.37) during week 5. During week 6, densities of parasitized nymphs were higher ($p < 0.05$) in the intercrop treatments (35.87 ± 40.73) than in the monocrop treatments (24.24 ± 28.55).

Numbers of fourth-instar *T. vaporariorum* were lower ($p < 0.05$) in the imidacloprid-treated intercrop (0.58 ± 1.73/plant) than the untreated intercrop (52.33 ± 45.92) during week 5. Numbers were not different between monocrop subplot treatments (6.15 ± 12.91) that week. During week 6, numbers of *T. vaporariorum* (20.61 ± 30.61) were not different among treatments. Numbers of fourth-instar *B. tabaci* (0.09 ± 0.47) were not statistically different ($p < 0.1$) during week 5. *B. tabaci* comprised 0.5% of the fourth-instars observed that week.

There were fewer ($p < 0.05$) tomato plants in the untreated subplot treatments (11.00 ± 7.92) than in the imidacloprid-treated subplots (19.38 ± 7.19).

The heavy rains associated with Hurricane Mitch presumably reduced arthropod populations. Beat cloth samples of tomato yielded few arthropods and almost no generalist predators.

Conclusions

The intercropping arrangements examined did not reduce densities of whitefly immatures in a consistent manner. Whitefly counts were characterized by extremely high variability, which may have obscured treatment differences. In the second bean crop of the diversity study and the bean crop of the mosaic study, both conducted during the rainy season, lower whitefly levels on intercropped plants resulted from reduced plant size and health. Plant size and whitefly densities were greater on intercropped than on monocropped tomato plants on some dates in the mosaic and corn/cilantro studies. Reduced plant quality among intercropping treatments is not uncommon in polyculture studies (Kareiva 1983).

Weather patterns in Guatemala were disrupted in 1998 by El Niño as they were throughout the world. Precipitation in the Salamá valley is typically highest in September, and declines throughout October. In 1998, precipitation was sporadic in September, and unseasonably heavy in October. Between 18 October, when bean was first sampled, and 30 October, 39.8 mm precipitation was recorded at the San Jerónimo weather station. During 31 October and 1 November, as Hurricane Mitch passed through the region to the south, 141 mm rain fell. From 2 November through 6 December, when the final sample was taken, 44.9 mm precipitation fell (Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología, San Jerónimo station).

The canopy provided by intercrop treatments in the rainy season may have offered some shelter to whitefly adults during the rainy season. This may have contributed to the higher whitefly levels observed on intercrop tomato in the mosaic and corn/cilantro studies on some dates.

Imidacloprid provided early season protection against whiteflies and other sucking insects which was essential for growing bean in the dry season. Rainy-season tomato treated with imidacloprid was more robust and had lower whitefly densities than untreated tomato. The detergent and oil rotation used on bean in the dry season caused phytotoxicity, but offered no protection from whiteflies and other sucking insects.

The failure of intercropping to reduce numbers of *Trialeurodes* and *Bemisia* may be related to their wide host range, their host-finding mechanisms, and their mobility. The disruptive crop hypothesis (Vandermeer 1989) is generally applied to specialist or oligophagous herbivores rather than polyphages like *Trialeurodes* and *Bemisia* (Andow 1991a, Power 1990). Andow (1991a) reports that population densities of polyphagous

arthropods in polyculture were higher than in monoculture 40.3% of the time, and lower in 28.4% of reported studies. However, some efforts to manage whiteflies through intercropping have been partially successful, particularly in the reduction of virus incidence (Al-Musa 1982, Schuster et al. 1996).

Intercropping with poor and non-hosts may not interfere with host-finding mechanisms of *T. vaporariorum* and *B. tabaci*. *Trialeurodes vaporariorum* and *B. tabaci* apparently do not respond to host-specific visual or olfactory cues (Mound 1962, Woets and van Lenteren 1976, van Lenteren and Woets 1977). They are attracted to the yellowish range of light spectra emitted by most vegetation (van Lenteren and Noldus 1990). *Trialeurodes vaporariorum* and *B. tabaci* require gustatory information to judge the suitability of a host, and do not reject a host until they have probed it (van Lenteren and Noldus 1990). It is unlikely that whiteflies can be confused or repelled from a cropped area by the volatiles or appearance of non-host plants. If host-finding cannot be manipulated at a distance, it also may be unlikely that whiteflies can be drawn away from a crop by the presence of a trap crop.

It seems probable that whitefly movement cannot be manipulated by intercropping with poor and non-hosts. Whiteflies are weak fliers and rely on wind for both short and long distance migration (Byrne et al. 1996). They move passively with air currents, probing plants as they come into contact with them (Byrne and Bellows 1991). Unlike stronger fliers, which might leave a cropped area after encountering a few non-hosts in succession (Bach 1980a, Risch 1981, Power 1990), whiteflies move from plant to plant within the field until they find an acceptable host (Byrne and Bellows 1991). Whitefly

populations that might therefore accumulate at higher densities on intercropped than monocropped hosts, if the host is planted at a lower density in the intercropped system.

It seems unlikely that intercropping alone can protect crops from whitefly damage. Crops such as tomato must be kept virus-free for 40-60 days after emergence in order to protect yield (Cubillo et al. 1994), and this can probably only be achieved over limited areas with fabricated devices such screened nurseries and floating row covers (Norman et al. 1993). Whitefly management in the tropics may require region-wide coordination of host-free periods, as practiced in the Dominican Republic (Polston and Anderson 1997), combined with the integrated pest management programs specifically designed for medium-scale and low resource farmers, such as those currently being implemented for tomato growers in Costa Rica (Hilje 1993, 1998).

Summary

The predominant whitefly species in the Salamá valley is *T. vaporariorum*. Whitefly populations were highest at the end of the dry season (May), lowest early in the rainy season (June-September), and increasing at the end of the rainy season (October-November). Observations of *B. tabaci* were low throughout the year. *Bemisia tabaci* on bean was estimated at 11% of the total population at the end of the dry season, 46% in the middle of the rainy season, when overall populations were at their lowest, and 0.5% on tomato at the end of the rainy season.

Treatment comparisons were difficult to interpret due to high variability among samples, and by intercrop competition, which reduced bean and tomato size and health in some studies. The intercropping arrangements examined either did not reduce whitefly densities consistently relative to monoculture, reduced whitefly numbers by stunting the

host, or in a some instances produced higher whitefly numbers than appeared in monoculture.

Row and mixed intercropping with poor and non-hosts did not reduce densities of whitefly immatures on bean or tomato compared to bean and tomato grown in monoculture. Imidacloprid effectively reduced whitefly immatures in dry and rainy seasons. Imidacloprid combined with intercropping offered no advantage over imidacloprid applied in monoculture. A detergent and oil rotation was ineffective in reducing damage from whitefly and other sucking insects in the dry season.

High numbers of beneficial insects were observed associated with flowering cilantro and rosa de jamaica early in the rainy season. However, efforts to increase beneficial insects in tomato with cilantro later in the rainy season failed because of heavy precipitation and disease. Parasitoids reared from whitefly nymphs on bean from May through July consisted entirely of *Encarsia pergandiella*, which was the only parasitoid species present during the entire sampling period. Members of the *Encarsia meritoria* species complex appeared in low numbers early in August, and were present throughout the rainy season. *Amitus fuscipennis* was reared from whiteflies on tomato in November, and achieved high levels in some treatments by early December. Parasitoid diversity was increased in the rainy season on tomato intercropped with rosa de jamaica and corn when compared to tomato grown in monoculture, or to tomato intercropped only with corn.

Table 4-1. Whitefly eggs and nymphs on bean under 2 cropping systems and 3 pesticide regimes. Diversity study, first bean crop.

		Egg			Nymph		
Wk	Pesticide	Monocrop	Intercrop	mean	Monocrop	Intercrop	mean
1[1]	Imidacloprid	46.38±44.68	43.18±35.08a[2]	44.78±39.68	-	-	-
	Detergent/oil	68.90±43.74	74.93±53.57ab	71.91±48.37	-	-	-
	Control	56.30±50.31	108.3±90.84b	82.30±77.11	-	-	-
	mean	57.19±46.48	75.46±68.53		-	-	
2	Imidacloprid	17.70±15.86	17.10±15.40	17.40±15.45a	5.53±5.00	13.23±17.24	9.43±13.13a
	Detergent/oil	31.33±24.62	28.93±18.62	29.96±21.09a	42.83±42.26	59.15±61.52	52.16±54.01c
	Control	62.43±49.36	62.90±43.88	62.70±45.60b	27.60±30.70	29.35±27.28	28.60±28.37b
	mean	35.21±36.38	36.31±34.52		23.34±32.36	33.94±43.82	
3	Imidacloprid	11.80±14.27	16.70±18.95	14.25±16.74a	8.08±11.40	7.05±9.28	7.57±10.28 a
	Detergent/oil	3.41±5.20	4.27±4.76	3.84±4.94 b	20.32±21.42	25.15±18.92	22.73±20.10b
	Control	6.57±8.92	10.55±24.57	8.56±18.36 ab	28.15±21.85	37.58±38.60	32.87±31.33b
	mean	7.26±10.59	10.51±18.54		18.85±20.32	23.26±27.98	
4[3]	Imidacloprid	279.50±535.02	2533.75±2292.44a	1406.63±1956.23	621.00±613.60	1547.25±1293.92	1084.13±1060.19a
	Detergent/oil	8.75±13.00	15.00±17.63 b	11.88±14.72	30.25±31.49	47.50±62.00	38.88±46.44 b
	Control	6.25±5.68	3.25±2.87 b	4.75±4.46	205.75±136.32	64.25±90.17	135.00±131.03b
	mean	98.17±309.93	850.67±1725.84		285.67±418.28	553.00±999.56	

5	Imidacloprid	19.21±32.05	23.41±45.87	21.31±38.98	3.00±2.65	11.72±29.46	7.36±21.04
	Detergent/oil	3.91±10.76	11.19±31.36	7.55±23.36	1.31±1.25	3.35±7.72	2.42±5.56
	Control	0.31±0.44	14.75±44.22	7.53±31.63	1.69±2.17	2.78±5.82	2.23±4.36
	mean	7.81±20.82	16.45±40.45		2.00±2.19	6.01±17.99	
6[2]	Imidacloprid	0	0.25±0.50	0.13±0.35	30.25±38.02	17.25±15.13	23.75±27.68
	Detergent/oil	0	0.25±0.50	0.13±0.35	2.50±3.11	14.00±16.73	8.25±12.73
	Control	0	0	0	13.25±23.19	3.00±2.45	8.13±16.22
	Mean	0	0.16±0.39		15.33±26.19	11.42±13.45	

[1]Means from weeks 1, 2, 3, and 5 represent the average count from one 3.35cm^2 upper stratum leaf disc punch and one 3.35 cm^2 lower stratum leaf disc punch.
[2]Data are means of 5 replications. Means in columns for a given week followed by the same letter are not significantly different ($p < 0.05$) according to Tukey's Studentized Range test. No letters present indicate no differences for that week. No differences ($p > 0.1$) between means in monocrop vs. intercrop treatments on any sampling date.
[3]Means from weeks 4 and 6 represent counts from 1 entire plant per replicate.

Table 4-2. Height and weight ($\bar{x} \pm$ SD) of bean plants under 2 cropping systems and 3 pesticide regimes. Diversity study, first bean crop.

		Height (cm)			Weight (g)		
Wk	Pesticide	Monocrop	Intercrop	mean	Monocrop	Intercrop	mean
3	Imidacloprid	8.19±2.76	8.70±2.75	8.44±2.73a[1]	-	-	-
	Detergent/oil	5.85±1.33	5.72±1.29	5.79±1.24b	-	-	-
	Control	5.98±1.18	5.99±1.72	5.99±1.46b	-	-	-
	Mean	6.67±2.15	6.80±2.40		-	-	
4	Imidacloprid	26.61±9.05	28.55±6.86	27.60±7.95a	71.50±62.34	105.80±58.94	88.65±59.08a
	Detergent/oil	13.39±3.36	11.85±2.95	12.60±3.21b	31.45±9.15	27.93±12.07	29.69±10.09b
	Control	10.88±3.51	11.45±4.10	11.15±3.76b	38.63±27.32	23.38±3.40	31.00±19.78b
	Mean	16.85±9.04	17.38±9.41		47.19±40.22	52.37±50.51	
5	Imidacloprid	-	-	-	158.50±120.77	152.50±72.98	155.50±92.43a
	Detergent/oil	-	-	-	25.95±14.68	36.75±17.79	31.35±16.16 b
	Control	-	-	-	26.25±7.68	29.25±10.69	27.75±8.76 b
	Mean	-	-		70.23±91.12	72.83±71.01	
6	Imidacloprid	46.75±15.78	55.00±4.40	50.88±11.59a	160.25±92.25	167.75±113.85	164.00±96.01a
	Detergent/oil	20.88±6.61	28.25±6.44	24.56±7.22 b	26.13±20.22	37.50±22.47	31.81±20.70 b
	Control	25.50±4.43	21.00±5.23	23.25±5.09 b	24.88±20.58	15.75±6.24	20.31±14.90 b
	Mean	31.04±14.96	34.75±16.04		70.42±83.37	73.67±92.72	

[1]Data are means of 5 replications. Means in columns for a given week followed by the same letter are not significantly different ($p < 0.05$) according to Tukey's Studentized Range test. No letters present indicate no differences for that week. No differences ($p > 0.1$) between means in monocrop vs. intercrop treatments on any sampling date.

Table 4-3. Whitefly egg and nymphs ($\bar{x} \pm SD$)[1] on tomato under 2 cropping systems and 2 pesticide regimes. Diversity study.

		Egg			Nymph		
Wk	Pesticide	Monocrop	Intercrop	mean	Monocrop	Intercrop	mean
1	Detergent/oil	4.31±9.99	1.58±2.39	3.14±7.72 a[2]	1.31±3.40	0.42±1.16	0.93±2.68
	Control	15.00±25.03	14.75±25.26	14.88±24.74b	1.63±2.58	2.25±4.78	1.94±3.79
	Mean	9.66±19.52	9.61±20.03		1.47±2.97	1.46±3.76	
2	Detergent/oil	50.50±41.35	65.33±106.25	56.86±68.42	31.25±21.82	21.33±35.23	27.00±26.08
	Control	578.00±899.20	105.50±56.95	341.75±641.64	132.00±167.48	53.00±47.23	92.50±121.49
	Mean	314.25±653.27	88.29±76.46		81.63±122.99	39.43±42.61	
3	Detergent/oil	3.58±5.38	9.22±17.06	6.00±11.85	7.00±7.07	21.00±19.91	13.00±15.37
	Control	1.50±2.31	1.00±2.37	1.25±2.31	9.83±8.32	6.25±4.61	8.04±6.83
	Mean	2.54±4.19	4.52±11.69		8.42±7.69	12.57±15.04	
4	Detergent/oil	-	-	-	0	0.67±1.41	0.29±0.96
	Control	-	-	-	0.17±0.58	0.33±0.65	0.25±0.61
	Mean	-	-		0.08±0.41	0.48±1.03	

[1] See text for sample units.

[2] Means in columns for a given week followed by different letters are significantly different ($p < 0.05$) according to analysis of variance. Absence of letters indicates no treatment differences ($p > 0.1$).

Table 4-4. Whitefly immatures and number of trifoliate leaves per plant on bean grown among senescing intercrops vs. monocrop. Diversity study, second bean crop.

Week		Egg	Nymph	Trifoliate
1	Monocrop	1.25±1.76	-	-
	Intercrop	2.00±2.38	-	-
	Mean	1.63±2.11	-	-
2	Monocrop	3.44±3.29	0.94±2.11	-
	Intercrop	2.75±2.11	1.25±1.34	-
	Mean	3.09±2.74	1.09±1.75	-
3	Monocrop	16.25±8.14a[1]	8.50±6.50	-
	Intercrop	8.25±6.32 b	6.13±3.64	-
	Mean	12.25±8.16	7.31±5.24	-
4	Monocrop	17.38±6.99a	22.25±13.02	7.88±2.53
	Intercrop	6.00±4.38 b	21.13±10.56	7.00±2.51
	Mean	11.69±8.12	21.69±11.47	7.44±2.48
5	Monocrop	6.63±6.02	37.50±26.27	11.25±3.94a
	Intercrop	6.25±6.11	34.75±29.48	8.50±2.20 b
	Mean	6.44±5.86	36.13±27.01	9.88±3.16
6	Monocrop	4.50±5.83	78.50±66.33	23.50±7.01a
	Intercrop	7.75±4.86	41.00±24.87	13.50±3.02b
	mean	6.13±5.45	59.75±52.12	18.50±7.34

[1] Means in the same column for a given week followed by a different letter are significantly different ($p < 0.05$) according to analysis of variance. The absence of letters indicates no treatment differences ($p > 0.1$).

Table 4-5. Whitefly immatures ($\bar{x} \pm$ SD/plant) and plant parameters of bean monocropped and mix intercropped with field corn and rosa de jamaica. Mosaic study.

	Egg		Nymph		Height (cm)		Trifoliates		Weight (g)	
Wk	Monocrop	Intercrop	Monocrop	Intercrop	Monocrop	Intercrop	Monocrop	Intercrop	Monocrop	Intercrop
1	31.83± 51.10	10.71± 13.32@[1]	-	-	11.56± 2.97	16.86± 2.49**[1]	-	-	-	-
2	46.56± 71.62	10.81± 11.84@	8.00± 11.31	2.12± 2.75*	14.34± 2.71	17.09± 2.31**	-	-	-	-
3	75.25± 120.44	9.88± 18.22*[1]	17.69± 30.24	5.81± 7.79	17.19± 3.17	18.00± 4.43	1.13± 0.81	0.50± 0.52**	-	-
4	111.13± 175.62	21.88± 18.02*	43.19± 63.19	8.31± 7.89*	21.13± 3.54	22.03± 4.17	2.88± 1.23	1.63± 0.62**	10.97± 5.58	4.02± 1.56 **
5	33.88± 54.44	22.75± 51.55	65.88± 55.22	10.13± 5.46*	22.19± 3.07	22.00± 4.06	4.50± 1.31	2.50± 0.76**	13.94± 6.51	5.84± 2.66**
6	7.25± 4.59	4.63± 5.78	133.25± 259.35	29.50± 40.02	27.75± 6.25	24.38± 7.86	6.25± 2.38	4.13± 2.17@	27.38± 17.85	11.14± 11.55**

[1]**, *, @ indicate that intercrop mean is significantly different from corresponding monocrop mean at $p < 0.01$, $p < 0.05$, and $p < 0.1$ respectively.

Table 4-6. Whitefly immatures ($\bar{x} \pm$ SD/plant) and plant parameters of tomato monocropped and mix-intercropped with field corn and rosa de jamaica. Mosaic study.

	Egg		Nymph		Height (cm)		Brances		Weight (g)	
Wk	Monocrop	Intercrop	Monocrop	Intercrop	Monocrop	Intercrop	Monocrop	Intercrop	Monocrop	Intercrop
1	0.25±	0.56±	0	0	13.13±	15.50±	-	-	-	-
	0.77	1.03			3.42	5.45				
2	147.81±	113.06±	0.13±	3.44±	13.81±	19.06±	4.88±	4.88±	-	-
	171.18	71.56	0.34	4.46**[1]	2.79	2.66**	0.72	0.62		
3	364.13±	347.75±	13.25±	41.63±	20.09±	26.88±	5.25±	4.88±	5.08±	5.00±
	505.88	244.57	15.58	35.77*[1]	4.94	4.46**	0.89	1.13	3.49	1.77
4	1351.25±	1788.25±	303.92±	502.0±	29.71±	37.46±	6.58±	6.67±	15.00±	14.46±
	998.20	807.93	334.91	283.05@[1]	6.73	6.71**	0.67	0.65	7.62	6.31
5[2]	0	0	160.58±	206.75±	52.67±	50.67±	7.25±	8.83±	93.92±	31.00±
			90.62	135.47	10.62	12.36	1.29	1.03**	49.78	9.76**
6[2]	0	0	115.92±	136.42±	-	-	-	-	-	-
			91.69	187.32						

[1]**, *, @ indicate that intercrop mean is significantly different from corresponding monocrop mean at $p < 0.01$, $p < 0.05$, and $p < 0.1$ respectively.

[2] Counts taken from lower third of plant only.

Table 4-7. Parasitoid complex by percent species, Mosaic experiment.

Species	Treatment	
	Monocrop	Intercrop
Encarsia pergandiella	88.4 (289)[1]	40.1 (219)
Encarsia meritoria complex	0.6 (2)	13.7 (75)
Amitus fuscipennis	11.0 (36)	46.2 (252)

[1] Number in parentheses represents total number of individuals from two sample dates (22 November 1998, 6 December 1998).

Table 4-8. Height and weight of tomato plants monocropped and intercropped with field corn, with and without imidacloprid.

		Height (cm)			Weight (g)		
Wk	Pesticide	Monocrop	Intercrop	mean	Monocrop	Intercrop	mean
2	Imidacloprid	21.91±4.94a[1]	21.22±7.21	21.56±6.09	-	-	-
	Untreated	16.29±5.39b	24.69±6.66	21.09±7.38	-	-	-
	mean	19.50±5.78	22.95±7.05		-	-	
3	Imidacloprid	29.03±10.29	33.06±7.06	31.05±8.92[a]	20.63±12.16	17.97±8.17	19.29±10.28a
	Untreated	21.00±7.35	24.44±7.26	22.96±7.37b	5.46±4.16	6.94±6.28	6.30±5.43 b
	mean	25.59±9.86	28.75±8.29		14.13±12.15	12.45±9.09	
4	Imidacloprid	40.38±7.78	49.56±8.84	44.97±9.34a	31.06±9.34	48.06±23.18	39.56±19.19a
	Untreated	26.58±5.16	35.00±9.83	31.39±8.99b	14.38±9.29	21.50±14.11	18.45±12.39b
	mean	34.46±9.64	42.28±11.75*[2]		23.91±12.39	34.78±23.06*	
5	Imidacloprid	65.00±9.81	68.00±7.65	66.50±8.74a	125.36±62.63	127.50±36.82	126.48±49.62a
	Untreated	55.89±8.48	57.92±7.33	57.05±7.70b	88.11±31.45	85.33±25.39	86.52±27.43 b
	mean	61.09±10.15	62.96±8.96		108.60±53.32	106.42±37.69	

[1]Means in the same column for a given week followed by a different letter are significantly different ($p < 0.05$) according to analysis of variance. The absence of letters indicates no treatment differences ($p > 0.1$).

[2]* Intercrop mean is significantly different ($p < 0.05$) from corresponding monocrop mean according analysis of variance.

Table 4-9. Whitefly eggs and nymphs ($\bar{x} \pm$ SD/plant) on tomato monocropped and intercropped with corn, with and without imidacloprid.

		Egg			Nymph		
Wk	Pesticide	Monocrop	Intercrop	mean	Monocrop	Intercrop	Mean
1	Imidacloprid	10.56±9.81	8.19±11.78	9.38±10.73 a[2]	0.13±0.34	0	0.06±0.25
	Untreated[1]	95.08±95.76	33.19±32.62	59.71±72.80b	0	0	0
	Mean	46.79±74.86	20.69±27.26		0.07±0.26	0	
2	Imidacloprid	79.00±77.00	66.25±59.02 a	72.63±67.79	0.88±1.63	0.31±0.87a	0.59±1.32
	Untreated	139.75±174.49	601.31±496.96b	403.50±451.35	0.92±1.24	5.38±9.50b	3.46±7.47
	Mean	105.04±128.98	333.78±441.67@[3]		0.89±1.45	2.84±7.12	
3	Imidacloprid	188.19±222.43	305.19±200.42	246.69±216.56	4.13±5.35	12.13±14.68	8.13±11.60 a
	Untreated	185.82±303.86	403.88±528.13	315.04±456.45	66.00±93.13	142.00±234.75	111.04±191.25b
	Mean	187.22±253.09	354.53±396.12		29.33±65.66	77.06±167.42	
4	Imidacloprid	825.63±821.51	804.13±497.59	814.88±656.21	248.38±237.51a	134.50±132.41a	191.44±194.85
	Untreated	429.83±441.12	1202.88±1844.78	871.57±1436.99	122.33±119.58b	491.75±415.42b	333.43±366.63
	Mean	656.00±692.49	1003.50±1321.40		194.36±200.16	313.13±350.36	
5[4]	Imidacloprid	66.83±220.28	1.00±1.59	33.92±156.00	260.67±213.49	81.25±69.40 a	170.96±180.28
	Untreated	4.75±8.39	0.25±0.87	2.05±5.61	201.38±131.89	284.83±189.47b	251.45±170.16
	Mean	42.00±170.56	0.62±1.31		236.95±183.53	183.04±174.02	
6[4]	Imidacloprid	0.33±0.78	0	0.17±0.56 a	112.83±60.59	65.42±46.32 a	89.13±58.04
	Untreated	78.78±163.51	31.36±104.02	52.70±132.43b	117.22±53.64	169.27±151.44b	145.85±118.27
	Mean	33.95±110.79	15.00±71.94		114.71±56.35	115.09±119.63	

[1] Untreated seedlings were produced in nurseries protected by fine mesh.
[2] Means in the same column for a given week followed by a different letter are significantly different ($p < 0.05$) according to analysis of variance. The absence of letters indicates no treatment differences ($p > 0.1$).
[3] @ intercrop mean is significantly different ($p < 0.1$) from corresponding monocrop mean according to analysis of variance.
[4] Counts from the lower third of the plant only.

Table 4-10. Parasitoid complex by percent species from tomato monocropped and intercropped with corn, with or without imidacloprid.

Species	Monocrop		Intercrop	
	Imidacloprid	Untreated	Imidacloprid	Untreated
Encarsia pergandiella	97.9 (187)[1]	99.4 (154)	92.2 (118)	96.2 (435)
Encarsia meritoria complex	0.5 (1)	0	1.6 (2)	0.7 (3)
Amitus fuscipennis	1.6 (3)	0.6 (1)	6.3 (8)	3.1 (14)

[1] Number in parentheses represents total number of individuals from two sample dates (19 November 1998, 2 December 1998).

CHAPTER 5
A COMPARISON OF SOME ARTHROPOD GROUPS ON MONOCROPPED AND INTERCROPPED TOMATO (*LYCOPERSICON ESCULENTUM* MILL.) IN BAJA VERAPAZ, GUATEMALA

Introduction

Intercropping is the agronomic practice of growing two or more crops simultaneously in the same field (Andrews and Kassam 1976). Intercropping and other forms of polyculture have been associated with reduced pest damage in some cropping systems (Andow 1991a). Root (1973) proposed two theories to explain why herbivore damage may be reduced by polyculture. The "resource concentration" hypothesis states that the ability of specialist herbivores to exploit a crop is reduced when that crop is mixed with non-hosts. Polyphagous herbivores may also be affected if intercropping with less attractive or non-hosts dilutes the time and energy invested in searching for acceptable main crops (Trenbath 1976). The "enemies" hypothesis suggests that the varied habitats and resources associated with polyculture may provide a stable supply of hosts and prey for natural enemies. Populations of beneficial insects might therefore be more stable in diverse cropping systems than in monoculture, enabling parasitoids and predators to reduce herbivore populations on main crops before they become economically damaging (Root 1973). Crops which support populations of natural enemies do so by offering alternative prey or hosts, or energy sources such as pollen or extra-floral nectaries (Sheehan 1986).

Materials and Methods

In 1998, field studies were carried out in the Salamá valley, a tomato-growing region in central Guatemala, to determine if intercropping with non- and poor hosts would reduce densities of immature whiteflies (Homoptera: Aleyrodidae) on tomato (*Lycopersicon esculentum* Mill.) (see chapter 4). Three pesticide subplot treatments were included to determine if the pesticide/intercrop combination offered an advantage over either strategy alone. Cilantro (*Coriandrum sativum* L.) was included as an intercrop in part because it was observed to support high densities of generalist predators, primarily *Geocoris* spp. (Hemiptera: Lygaeidae) and Coccinellidae (Coleoptera) during visits to farms in the region. A few months into the study, predatory and parasitic Hymenoptera and Coccinellidae were observed feeding on extra-floral nectaries at the base of the leaf and on the corolla of rosa de jamaica (*Hibiscus sabdariffa* L.) (Malvaceae), another species intercropped with tomato.

In order to determine if levels of generalist predators were higher on tomato intercropped with cilantro, rosa de jamaica, and velvetbean (*Mucuna deeringiana* (Bort.) Small) than on monocropped tomato, beat cloth samples were taken from all crops.

Location

The research was carried out at the Instituto de Ciencia y Tecnología Agrícolas (ICTA) field station in San Jerónimo (15° 03' N, 90° 15' W), Baja Verapaz, Guatemala. ICTA is the government agricultural research institute of Guatemala. The station is 1000 m above sea level. The area is classified as subtropical dry forest under the Holdridge system (Holdridge 1967, de la Cruz 1982).

Research Design

A split-plot design was used with two whole plot treatments (monocrop and intercrop tomato) and three subplot pesticide treatments (imidacloprid, a detergent/oil rotation, and control). Each treatment was replicated four times.

Whole Plot Treatments

Whole plots contained nine rows, 17 m in length. Between row spacing was 1.0 m. Monocrop plots consisted of eight rows of tomato. Intercrop plots consisted of nine rows of a tomato/intercrop mix. Five intercrop species were planted in alternating rows with tomato in the following order: velvetbean, rosa de jamaica, cilantro, cabbage (*Brassica oleracea* L.), and corn (*Zea mays* L.). These crops were chosen to represent diversity in plant architecture, plant chemistry, and uses. Aside from velvetbean, which is used as a forage and green manure, each crop has domestic and market value.

The cultivar of tomato used was 'Elios' (Petoseed, Saticoy, CA). Cultivar information was not available for cilantro, velvet bean, and rosa de jamaica, which were grown from locally-acquired seed. Corn and cabbage were not sampled for this study.

Spacing between plants was 20 cm for cilantro and velvetbean and 40 cm for tomato and rosa de jamaica. Cilantro and rosa de jamaica were planted 25 March. Velvetbean was planted 26 March. Tomato in the imidacloprid treatment was transplanted 28 April. Tomato in the untreated and detergent/oil treatments was transplanted 6 May.

Subplot Treatments

Each whole plot was divided into 3 sections of 5.67 m in length. These sections were randomly assigned to the imidacloprid treatment, the detergent and oil treatment, or the control.

Imidacloprid (Confidor 70 WG, Bayer, Germany) was prepared at a rate of 0.73 g/liter of water. Approximately 10 cc of this mixture (73 mg imidacloprid) was applied to the base of each tomato plant at each application. Tomato seedlings received one imidacloprid application in the nursery, and were treated one and three weeks after transplanting.

Olmeca® vegetable oil (Olmeca S.A., Guatemala) and Unox® laundry detergent (Quimicas Lasser S.A., El Salvador) were applied at a rate of 1%, or 16 cc/16 liter spray tank (Calderón et al. 1993). An elbowed nozzle attachment was used to apply the mixture to the lower surface of leaves. Detergent or oil was applied in rotation every five days.

Crop Management

Crops were managed according to local practices (ICTA 1993, Superb 1997). Fungicides were applied with a backpack sprayer on a weekly basis to tomato to control foliar and root pathogens once the rains began in May. No additional pesticides were applied to tomato other than those from assigned treatments. No pesticides were applied to cilantro, rosa de jamaica, or velvetbean. A furrow irrigation system was used as needed.

Beat Cloth Samples

On 3 July, one beat cloth sample per subplot was taken from each row of cilantro, rosa de jamaica, and velvetbean. One beat cloth sample was taken from intercrop tomato in rows two and four of each subplot. These rows were situated between velvetbean and rosa de jamaica and rosa de jamaica and cilantro, respectively. One beat cloth sample was taken from monocrop tomato in rows two and four of each subplot. Tomato was producing flowers and green fruit, and cilantro was flowering when the samples were collected. Rosa de jamaica and velvetbean had foliage only.

A 1.0-m x 0.75 m plastic sheet (Olefinas, S.A, Guatemala) was spread out on a wooden board at the base of the crop row. The plants were struck manually four times to dislodge arthropods toward the sheet, which was then folded quickly into a ball and sealed with masking tape. The samples were first refrigerated, then transported to the Universidad del Valle in Guatemala City.

At the university, the samples were frozen to kill all arthropods, then opened for identification. Arthropods were grouped as spiders, insect predators, hemipteran herbivores, and Coleoptera. Spiders were preserved in 80% ethanol and mailed to the Division of Plant Industry, Gainesville, FL, where they were classified to family or genus. Most insects were classified to family. Pentatomids were grouped as phytophagous or predaceous based on buccal morphology (Slater and Baranowski 1978).

Statistical Analysis

Analysis of variance for a split-plot design (SAS 1996) was used to compare total number of spiders, hemipteran herbivores, and Coleoptera among tomato treatments. Tukey's studentized range mean separation procedure was used to distinguish among subplot treatments, when appropriate. Analysis of variance for randomized complete block was used to compare total number of spiders, insect predators, hemipteran herbivores, and Coleoptera among cilantro, rosa de jamaica, velvetbean, and unsprayed, intercropped tomato. Tukey's studentized range test was used to distinguish host differences when appropriate.

Results

Insect predators consisted primarily of both adult and immature *Geocoris* (Lygaeidae), assassin bugs (Reduviidae), and ladybird beetles (Coccinellidae) (Table 5-1). The most common spiders were *Misumenops* sp. (Thomisidae), members of the Oxyopidae, and *Pardosa* sp. (Lycosidae) (Table 5-2). Herbivorous hemiptera consisted

primarily of *Engytatus modesta* (Distant) (Miridae), the tomato bug, found predominantly on tomato (Table 5-3). About 68% of the Coleoptera recovered belonged to the Chrysomelidae and Elateridae (Table 5-4). Proportions of various groups were influenced by the fact that four times as many samples were taken from tomato (48) as from each of the other crops (12). Sweep netting and other sampling methods would have provided estimates of different arthropod groups, such as the Hymenoptera observed on rosa de jamaica.

There were no differences ($p > 0.1$) between monocropped and intercropped tomato in numbers of spiders or Coleoptera. There were too few insect predators on intercropped and monocropped tomato for meaningful comparisons. Spiders were the primary predatory group found on tomato. Spider levels were higher ($p < 0.05$) on unsprayed tomato than on tomato that had been treated with imidacloprid or the detergent and oil rotation (Table 5-5). Numbers of hemipteran herbivores were higher ($p < 0.1$) on tomato treated with detergent and oil than the other two treatments. Hemipteran herbivores consisted primarily of *Engytatus modesta*, which was higher ($p < 0.05$) on tomato treated with the detergent and oil rotation (12. 50 ± 14.13 per beat cloth) than on untreated tomato (6.06 ± 5.37). Densities of *E. modesta* on tomato treated with imidacloprid were intermediate (8.56 ± 7.68).

There was no difference ($p > 0.1$) in the number of spiders among cilantro, rosa de jamaica, velvetbean, and unsprayed, intercropped tomato (Table 5-6). Levels of insect predators were higher ($p < 0.05$) on cilantro than on the other three crops. Hemipteran herbivores were more numerous ($p < 0.05$) on intercropped, unsprayed tomato than on the other three crops. This difference was due to high densities of *Engytatus modesta* on tomato. Beetle densities were higher ($p < 0.05$) on rosa de jamaica and velvetbean than on unsprayed, intercropped tomato.

Some of the families of Coleoptera collected contain both phytophagous and predaceous members. The Cleridae, Histeridae, and Staphylinidae are primarily predaceous, and the Mordellidae contains some predaceous groups (Borror et al. 1989). Aside from one staphylinid, all of the Coleoptera in these families were found on cilantro. Their status as predators was not determined, but it would not have affected cilantro's standing as the crop supporting the highest densities of insect predators (Table 5-6). Lampyrids and meloids have predatory larvae, but only adults were collected.

Discussion

It is noteworthy that the arthropod groups on tomato were apparently unaffected by the proximity of different crops supporting distinct arthropod communities. It is possible that densities of generalist predators could be increased on tomato by intercropping with higher densities of cilantro. However, the assumption that beneficial insects will move from intercrops to main crops is not always valid (Bugg et al. 1987, Corbett and Plant 1993). The data demonstrate the predominance of spiders as predators on tomato, and indicate the negative effect of some pesticides on spider numbers. The results suggest that cilantro may be a useful crop for augmenting levels of generalist predators in some cropping systems, although movement to target crops could be problematic.

Table 5-1. Insect predators recovered from samples collected on four crops, Baja Verapaz, Guatemala.

Family	Individuals	Percent	Crops
Geocoris (Lygaeidae)	46	38.3	Cilantro, rosa de jamaica, tomato, velvetbean
Reduviidae	27	22.5	Cilantro, rosa de jamaica, tomato, velvetbean
Coccinellidae	18	15.0	Cilantro, rosa de jamaica, tomato, velvetbean
Cicindellidae	16	13.3	Velvetbean
Syrphidae	9	7.5	Cilantro, tomato,
Chrysopidae	2	1.7	Rosa de jamaica, tomato
Pentatomidae	2	1.7	Tomato, velvetbean

[1]Four times as many beat cloth samples were taken from tomato (48) as from each of the other crops (12).

Table 5-2. Spiders recovered from samples collected on four crops, Baja Verapaz, Guatemala

Family[2]	Genus	Individuals	Percent	Crops[1]
Thomisidae	*Misumenops*	34	31.2	Cilantro, tomato, velvetbean
Lycosidae	*Pardosa*	18	16.5	Cilantro, tomato, velvetbean
Oxyopidae	spp.	11	10.1	Tomato
	Oxyopes	11	10.1	Cilantro, rosa de jamaica, tomato
Tetragnathidae	*Tetragnatha*	8	7.3	Tomato
Theridiidae	*Theridion*	7	6.4	Rosa de jamaica, tomato, velvetbean
Salticidae		6	5.5	Cilantro, tomato
Oxyopidae	*Peucetia*	4	3.6	Tomato
Araneidae		3	2.75	Cilantro, tomato
Philodromidae		2	1.8	Cilantro, tomato
Theridiidae	*Coleosoma*	2	1.8	Tomato
Corinnidae	*Meriola*	1	0.9	Velvetbean
Dictynidae		1	0.9	Tomato
Liniphiidae	*Florenda*	1	0.9	Tomato

[1]Four times as many beat cloth samples were taken from tomato (48) as from each of the other crops (12).

Table 5-3. Hemipteran herbivores recovered from samples collected on four crops, Baja Verapaz, Guatemala.

Family	Individuals	Percent	Crops[1]
Miridae	657	92.0	Cilantro, rosa de jamaica, tomato, velvetbean
Pentatomidae	19	2.7	Cilantro, tomato, velvetbean
Lygaeidae	14	2.0	Tomato, velvetbean
Pyrrhocoridae	13	1.8	Rosa de jamaica, velvetbean
Largidae	7	0.9	Cilantro, tomato
Coreidae	5	0.7	Tomato

[1]Four times as many beat cloth samples were taken from tomato (48) as from each of the other crops (12).

Table 5-4. Beetles recovered from beat cloth samples collected on four crops, Baja Verapaz, Guatemala.

Families	Individuals	Percent	Crops[1]
Chrysomelidae	49	43.4	Cilantro, rosa de jamaica, tomato, velvetbean
Elateridae	28	24.8	Rosa de jamaica, velvetbean
Anthicidae	8	7.1	Cilantro, rosa de jamaica
Meloidae	7	6.2	Cilantro, velvetbean
Erotylidae	4	3.5	Rosa de jamaica, tomato, velvetbean
Nitidulidae	3	2.7	Cilantro, rosa de jamaica
Cleridae	3	2.7	Cilantro
Lampyridae	2	1.8	Tomato
?	2	1.8	Cilantro
?	2	1.8	Cilantro
Staphylinidae	1	0.9	Tomato
Tenebrionidae	1	0.9	Velvetbean
Histeridae	1	0.9	Cilantro
Mordellidae	1	0.9	Cilantro
?	1	0.9	Cilantro

[1]Four times as many beat cloth samples were taken from tomato (48) as from each of the other crops (12).

Table 5-5. Numbers of arthropods per 0.75 m^2 beat cloth sample collected from tomato[1] under 3 pesticide regimes, Baja Verapaz, Guatemala

Pesticide	Spiders	Hemipteran herbivores	Beetles
Imidacloprid	0.81±0.98a[2]	9.67±8.76a	0.40±0.74a
Detergent/oil	1.07±1.27a	13.36±14.32b	0.29±0.61a
Control	2.12±1.67b	7.50±5.87a	0.33±0.62a

[1] There were no differences ($p < 0.1$) between monocropped and intercropped tomato.
[2] Data are means ± SD of eight replications (two main plot treatments and four replications). Means in columns followed by the same letter do not differ ($p < 0.1$) according to Tukey's studentized range test.

Table 5-6. Numbers of arthropods per 0.75 m^2 sample collected on four crops [1], Baja Verapaz, Guatemala

	Spiders	Insect predators	Hemipteran herbivores	Beetles
Tomato	1.75±1.39a[2]	0.75±0.71b	6.25±4.89a	0.33±0.82b
Cilantro	3.75±3.40a	6.50±5.26a	2.25±0.96b	2.00±2.16ab
Rosa de jamaica	0.74±0.50a	1.25±0.50b	2.25±3.20b	5.50±3.11a
Velvetbean	1.25±0.50a	1.50±1.00b	1.25±0.96b	4.00±1.83a

[1]Comparisons based on samples taken from unsprayed intercropped tomato and associated crops.
[2] Data are means ± SD of four replications. Means in columns followed by the same letter do not differ ($p < 0.1$) according to Tukey's studentized range test.

CHAPTER 6
METHODS FOR SAMPLING IMMATURE STAGES OF *BEMISIA ARGENTIFOLII* (HOMOPTERA: ALEYRODIDAE) ON BEAN (*PHASEOLUS VULGARIS* L.)

Introduction

Bemisia argentifolii Bellows & Perring (also known as *Bemisia tabaci* (Gennadius) strain B) is a serious economic pest of agronomic and horticultural crops throughout warm regions of the world (Brown et al. 1995). *Bemisia argentifolii* vectors numerous geminiviruses (Hiebert et al. 1996), inflicts mechanical damage (Schuster et al. 1996), and causes plant disorders (Shapiro 1996) among a wide range of plant groups.

Methods for sampling adult and immature whiteflies have been developed on some crops to establish economic thresholds and to test hypotheses related to control measures (Butler et al. 1989, Ekbom and Rumei 1990, Naranjo 1996, Ohnesorge and Rapp 1986a). Sampling plans for *Bemisia* egg and nymph stages have been developed for cotton (*Gossypium hirsutum* L.) (von Arx et al. 1984, Naranjo and Flint 1994, Ohnesorge and Rapp 1986b), cantaloupe (*Cucumis melo* L.) (Gould and Naranjo 1999, Tonhasca et al. 1994a, 1994b), tomato (*Lycopersicon esculentum* Mill.) (Carnero and González-Andujar 1994, Ohnesorge et al. 1980, Pernezny et al. 1995, Schuster 1998) and peanut (*Arachis hypogea* L.) (Lynch and Simmons 1993, McAuslane et al. 1993).

Sampling methods for *Bemisia* are determined by the behavior and biology of the insect and by the phenology of the crop being sampled (Naranjo 1996). Female whiteflies tend to oviposit on the underside of young leaves in the upper plant canopy (van Lenteren

and Noldus 1990). Upon emergence, first instars tend to move a short distance from the egg to find a feeding site (Byrne and Bellows 1991, Price and Taborsky 1992), although they are capable of moving within and between plants to find healthy feeding sites (Summers et al. 1996). Subsequent instars are sessile. Therefore nymphs usually complete their development on the leaf where they were oviposited, and the age of the nymph tends to correlate with the age of the plant leaf (Ekbom and Rumei 1990). Estimates of egg density are usually taken from upper stratum leaves, and nymph densities are estimated from the middle or lower canopy, depending on the host (Ohnesorge et al. 1980, Naranjo and Flint 1994, Schuster 1998).

Whitefly nymphs are susceptible to parasitism in early instars (Gerling 1990), but symptoms of parasitism are not obvious until the third or fourth instar. Mycetomes become asymmetrical in parasitized nymphs, and in later stages the parasitoid larva or fully-formed adult can be seen clearly through the cuticle (McAuslane et al. 1993). Therefore, estimates of parasitism are usually taken from the portion of the plant canopy containing the oldest nymphs.

In the final stage of healthy fourth-instar *Bemisia* nymphs, the red eyes of the pharate adult become apparent (Byrne and Bellows 1991). Therefore, this stage can be used to estimate the number of nymphs that have successfully completed development. Several genera and species of whitefly can only be identified with the exuvia of this final instar (the "pupal case") (Byrne and Bellows 1991). Location of the most representative stratum for final instar nymphs is necessary when species identification is required, such as in areas with mixed whitefly populations.

Populations of whitefly immature stages display high degrees of aggregation within individual leaves and within the plant canopy (Naranjo 1996). This tends to increase the sampling effort required to achieve acceptable population estimates for all stages of whiteflies (van Lenteren and Noldus 1990). However, the distribution of distinct immature stages throughout the plant canopy may permit the optimization of sampling resources through stratified sampling plans (Cochran 1963).

Common bean (*Phaseolus vulgaris* L.) yields throughout Latin America and the Caribbean Basin have been severely reduced by geminiviruses transmitted by *Bemisia* (Brown and Bird 1992). Bean golden mosaic reached epidemic levels in south Florida for the first time in 1993 (Blair et al. 1995). The development of whitefly management programs for bean will require effective sampling methods, particularly for host plant resistance studies (Ekbom and Rumei 1990). However there is little information available for sampling *Bemisia* on bean.

The following study was carried out to develop a preliminary plan for sampling whitefly immatures on bean. The purpose of the study was to determine the most representative stratum from which to sample eggs, nymphs, parasitized nymphs, and red-eyed nymphs of *B. argentifolii* on bean, and to determine how well two distinct sample units, a whole leaf or a disc punched from a leaf, served as predictors for whole plant densities of these immature stages.

Materials and Methods

Research Design and Plot Management

The experiment was carried out at the University of Florida Green Acres Agronomy Research Farm northwest of Gainesville, FL (29°40'N, 82°30'W). 'Espada'

garden bean (Harris Seed, Rochester, NY) was used. Bean in some plots was intercropped with rows of field corn (*Zea mays* L.) or eggplant (*Solanum melongena* L.) to test for intercropping effects, the results of which are reported elsewhere (see chapter 3). Bean was grown in a randomized complete block design of five blocks, each containing three plots of bean with various intercrop treatments (corn, eggplant, control). Whitefly densities on bean were not significantly affected by intercrop treatments, allowing counts on bean from the intercrop treatments to be pooled for this study. Therefore, whiteflies were sampled from bean in 15 plots.

Each plot contained 14 rows, 6.1 m in length with 0.9 m between rows. Spacing between bean plants within each row was 10 cm. Beans were planted 15 September and fertilized with 0.37 kg of 15-0-14 (N-P_2O_5-K_2O) per row on 23 September and 12 October. Overhead irrigation supplemented rainfall. Weeding was mechanical or by hand. No pesticides were applied to the bean crop.

Sampling

Bean was sampled using three sample units: whole plant, whole leaf, and disc punched from a leaf. For each sample unit, only the underside of the leaf was examined (Ekbom and Rumei 1990). Whole plant sample units consisted of the examination of all fully expanded leaves. Whole leaf sample units consisted of the examination of the central leaflet of a trifoliate from the upper, middle, and lower plant canopy. Hereafter, these three levels will be referred to as the upper, middle, and lower stratum. Disc punch samples were taken from the same strata as whole leaf samples. They were made by pressing a 3.35-cm^2 cork borer (McAuslane et al. 1995) into the lower right quadrant on the underside of the leaf.

Bean was sampled each week from 22 September through 11 November, except 29 September. On 22 September, when plants were in the cotyledonary stage, eight plants were collected from each plot. Disc and whole leaf counts were taken from each cotyledon leaf. From 8 October through 11 November, stratified disc punch samples were taken from four plants. Whole leaf samples were gathered from two of these plants, using the same leaves from which disc counts had been taken. One of these two plants was used to gather whole plant counts.

The area of each leaf used for whole leaf or whole plant sampling was recorded using a LI-COR portable leaf area meter (model LI-3000A, LI-COR Inc., Lincoln, NE). Disc, whole leaf, and whole plant counts were analyzed on a per cm^2 basis.

Leaves were examined using a stereoscope and fiber-optic light. Total numbers of *B. argentifolii* eggs, nymphs, parasitized nymphs, red-eyed nymphs, and total immature stages were recorded for each disc, leaf, and plant.

Statistical Analysis

Densities of *B. argentifolii* eggs, nymphs, parasitized nymphs, red-eyed nymphs and total immature stages on disc and whole leaves were compared across strata using analysis of variance. Densities of immature stages were then compared between strata using a pair-wise t-test (PROC GLM, SAS version 6.11, SAS Institute 1996). Because of the large number of comparisons made, the α-level was adjusted using the Bonferroni procedure (SAS 1996). Means and coefficients of variation (cv) were compared in order to determine the most appropriate stratum for sampling different immature stages. The regressions of whole plant counts on whole leaf counts and on disc counts were determined for each response on each stratum. Regression equations and size of r^2 values

were used to evaluate disc and leaf samples as predictors of whole plant counts. For comparison with existing literature, Taylor's Power Law parameters (Taylor 1961, 1984) were calculated for egg and nymph data from upper stratum disc units, lower stratum whole leaf units, and whole plant sample units.

Results and Discussion

Whole Plant Samples

Total leaf area per plant increased from weeks 1-7 (Table 6-1). Egg and nymph densities were highest during the first and third weeks of sampling, respectively, and declined over subsequent weeks. Observations of parasitized nymphs occurred first during week 3 and increased slightly over time. Observations of red-eyed nymphs increased from weeks 3-6, then declined. Density of total immature stages peaked during week 3 and declined over subsequent weeks. Coefficients of variation for whole plant data did not show a clear trend over time for any immature stage (Table 6-1), although they tended to be lowest for most stages during weeks 5-7.

Disc Samples

Egg densities were highest in the upper stratum across sampling dates (Table 6-2). Coefficients of variation were lowest in the middle stratum when the crop was young (weeks 3-4), but lowest in the upper stratum from week 5 onward. Regression of whole plant on disc punch counts produced significant regression equations in middle strata from weeks 3-5, and in upper or mid strata from weeks 6-8.

Nymph densities were consistently higher ($p < 0.05$) in mid and lower strata than in the upper stratum. Nymph densities were not usually significantly different between middle and lower strata, but there was a tendency in later weeks for the highest nymph

densities to shift from the lower stratum to the middle stratum. Coefficients of variation were consistently lower in the lower stratum. Significant ($p < 0.10$) regression equations were derived on only a few dates for mid or lower strata.

Parasitized nymphs were observed on the lower stratum from weeks 3-8, and on the middle stratum from weeks 6-8. Parasitized nymphs were never observed in the upper stratum disc counts. Coefficients of variation for parasitized nymph samples were always very high ($\geq 243\%$). However, the regressions of whole plant counts on leaf disc counts from the lower stratum were significant ($p < 0.05$) each week (3-8) for parasitized nymphs.

Red-eyed nymphs were observed on the lower stratum from weeks 3-8, and on the middle stratum during weeks 5-7. Coefficients of variation were typically high (>200%). Regressions of whole plant on disc counts were rarely significant.

The observation of highest egg densities in the upper stratum is consistent with the tendency of *Bemisia* females to oviposit on young leaves (Ekbom and Rumei 1990). Naranjo and Flint (1994) and Schuster (1998) reported higher coefficients of variation for eggs in the uppermost branch than from the branches immediately below, as we observed during the first weeks of sampling. This may be because fully expanded new leaves are highly attractive for oviposition, while those still expanding are not, producing both very high counts and zero counts in the upper stratum. The data suggest that estimates of egg density should be taken from the upper stratum, where eggs are most prevalent, but that intense sampling may be required because of high count variability.

Except for very late in the season, means tended to be highest and coefficients of variation lowest for nymphs in the lowest stratum. It may be advisable to focus sampling

efforts for nymphs on the lower stratum, because this stratum provided the best information on parasitized and red-eyed nymphs. It would therefore be possible to limit disc sampling to the upper stratum for eggs and lower stratum for other stages. However, a researcher primarily interested in estimating densities of nymphs rather than parasitized or red-eyed nymphs should focus on the middle stratum as the bean crop ages.

Overall immature counts shifted from being highest in the lower stratum in weeks 2-3 to highest in the mid and upper strata on week 6. There was no difference in pooled immature densities across strata on weeks 5, 7, or 8. The relatively even distribution of immature forms throughout the plant indicates the ability of the whitefly to exploit the entire plant habitat as leaf area increases. Coefficients of variation for pooled immatures tended to be lower in the lower stratum. Significant regressions of whole plant on disc counts occurred at times on all strata, but did not occur consistently on any given stratum.

Whole Leaf Samples

Patterns among whole leaf samples were similar to those found in disc samples. Egg densities tended to be highest in the upper stratum, but were significantly higher ($p < 0.05$) than middle stratum densities only during weeks 5-7 (Table 6-3). Coefficients of variation were lowest in the middle stratum during the first weeks of sampling, but tended to be lowest in the upper stratum in later weeks. Regression equations of whole plant on whole leaf egg counts were significant ($p < 0.05$) for upper and middle strata for most weeks. For example, the regression of whole plant egg counts on upper stratum whole leaf egg counts for week 4 is shown in Figure 6-1.

When plants were young (weeks 3-4), the highest ($p < 0.05$) nymph densities were found in the lower stratum. Coefficients of variation were consistently lowest in the

lower stratum. From weeks 5-7, densities in the middle and lower strata were not significantly different. As was observed with the disc sample units, nymph densities were highest in the middle stratum by week 8. Regression equations relating whole plant to whole leaf counts were significant for both middle and lower strata on most sampling dates.

Densities of parasitized nymphs were highest in the lower stratum from weeks 4-6, but not significantly different from middle stratum densities during weeks 7-8. Coefficients of variation were always lowest in the lower stratum. Regressions of whole plant on whole leaf counts were significant in the lower stratum each week, but they were not significant in other strata on any date.

Red-eyed nymphs were found in the lower stratum during weeks 3-8, and in the middle stratum from weeks 6-8. Densities of red-eyed nymphs were significantly higher in the lower stratum than the middle stratum on week 6, but not significantly different between strata on weeks 7-8. Coefficients of variation were always lowest in the lower stratum. Regression equations were significant in the lower stratum on weeks 4-6 and week 8.

Pooled immature counts were highest in lower strata early in the study (weeks 3-4), but even across strata for most of the remaining weeks. Coefficients of variation were similar across strata for pooled immature counts, but tended to be lowest in the lower stratum. Regressions of whole plant on whole leaf counts for pooled counts were significant in two or more strata for each week of sampling.

The parameters for Taylor's power law (Taylor 1961, 1984) for egg and nymph counts from disc, whole leaf, and whole plant sample units are shown in Table 6-4. The *b*

coefficients calculated for eggs and nymphs are lower than those reported by Naranjo and Flint (1994) and Schuster (1998), and suggest a distribution approaching random for disc and whole leaf egg counts. The greater degree of aggregation among nymphs than eggs indicated by lower *b* values for eggs is inconsistent with what is known about whitefly biology (Ekbom and Rumei 1990). However the coefficients of variation observed in our study are consistent with those reported by Naranjo and Flint (1994) and Schuster (1998) for whitefly eggs and nymphs.

Time Costs and Conclusions

The time required to examine whole plants, feed leaves through the leaf area meter, and record observations ranged from about 40 minutes per plant when plants were three weeks old to about 70 minutes per plant when plants were five weeks or older. About 15 minutes were needed to process two sets of whole leaf counts from three strata each week. Four sets of disc counts from three strata consistently required 8-10 minutes.

Examination of the whole plant is too costly in terms of time for this to be used as the sample unit for most sampling programs. However, some degree of whole plant sampling may be required to determine the range of branches or strata in which the life stage of interest will be found. Whole plant sampling is essential if an absolute estimate is required. Therefore it will be impractical to obtain an absolute estimate in most situations.

Stratified whole leaf samples gave better estimates than disc samples in that coefficients of variation tended to be lower, regressions with whole plant counts were significant more often, and the r^2 values from these regressions tended to be higher. However, the improved sampling parameters derived from whole leaf samples may not

justify the extra time required to gather them, or the necessity of possessing a leaf area meter. Counts taken from a whole leaf must be divided by the leaf area prior to analysis, which is time-consuming. Disc counts share a common density when they are recorded. The time required to take whole leaf samples could be invested into improving the quality of disc samples by taking more disc samples from the same leaf or from additional plants. Additional studies to obtain more extensive data on Taylor's power law parameters may be useful for assessing and comparing the precision of specific sampling plans.

Our data indicate that the upper stratum of the bean plant offers the best area from which to sample *B. argentifolii* eggs. The increase in egg density in the middle stratum probably occurs too late in the season to be valuable for estimates of oviposition. The best estimates of nymphs, parasitized nymphs, and red-eyed nymphs were found in the lower stratum.

Summary

Eggs and nymphs of *B. argentifolii* were sampled on bean using whole plant examinations and discs punched from leaves or whole leaf sample units taken from three strata. Egg densities were highest in the upper stratum, but more variable than counts from the middle stratum during the first weeks of sampling. The best estimates for densities of nymphs, parasitized nymphs and red-eyed nymphs were taken from the lowest stratum. Highest nymph densities shifted toward the middle stratum during final weeks of sampling. Pooled counts of immature stages demonstrate the ability of the whitefly to exploit the entire plant canopy as the bean crop grows. However, too much information is lost for pooled counts to be useful in management programs.

Distribution patterns of immature stages were similar for disc punch and whole leaf sample units. However, the additional time required to process whole leaf samples was not justified by the quality of the estimates when compared to estimates from disc punch samples. Some whole plant sampling may be necessary to determine the range of branches from which to sample life stages of interest with disc punches.

Table 6-1. Immature *B. argentifolii* on whole bean plants, fall 1996 -- mean numbers/cm^2 and coefficients of variation (CV)

		Eggs		Nymphs[2]		Parasitized nymphs		Red-eye nymphs		Total	
Week	Plant area[1]	mean	CV	mean	CV	mean	CV	mean	CV	mean	CV
1	24	1.03	65	0	-	0	-	0	-	1.03	65
3	315	0.85	51	0.94	63	0.003	299	0.001	387	1.79	55
4	386	0.56	63	0.89	47	0.01	75	0.004	324	1.47	49
5	525	0.39	36	0.63	61	0.009	117	0.006	138	1.04	42
6	464	0.43	49	0.57	41	0.01	104	0.02	81	1.03	34
7	552	0.37	106	0.46	44	0.02	102	0.01	78	0.86	63
8	486	0.14	106	0.36	71	0.04	94	0.005	139	0.55	76

[1]Represents mean leaf area in cm^2 for 15 bean plants.
[2]Includes all nymphs except parasitized and red-eyed nymphs.

Table 6-2. Immature *B. argentifolii* on bean sampled with disc punches from three strata –mean numbers per cm^2, coefficients of variation, and r^2 values[1]

		Eggs			Nymphs[2]			Parasitized nymphs			Red-eye nymphs			Total		
Wk	Stratum	Mean	CV	r^2	Mean	CV	r^2	Mean	CV	r^2	Mean	CV	r^2	Mean	CV	r^2
1	first true leaves	1.38	92	ns[4]	0	-	-	0	-	-	0	-	-	1.38	92	ns
3	upper	1.35a[3]	97	ns	0.19a	331	ns	0a	-	-	0a	-	-	1.54a	109	ns
	middle	1.07a	78	0.27*	3.37b	61	0.26*	0.02a	401	0.68**	0.03a	774	ns	4.47b	52	0.42**
4	upper	1.35a	128	ns	0.21a	209	ns	0a	-	ns	0a	-	-	1.56a	125	0.43**
	middle	0.72b	119	0.31*	1.46b	117	0.44**	0a	-	ns	0a	-	-	2.16a	96	0.61**
	lower	0.49b	149	ns	2.97c	68	ns	0.10b	274	0.21*	0.13a	323	0.78**	3.58b	68	ns
5	upper	1.55a	109	ns	0.21a	216	ns	0a	-	ns	0a	-	-	1.76a	97	ns
	middle	0.56b	172	0.23+	1.04b	123	0.53**	0a	-	ns	0.03a	543	ns	1.62a	96	0.36*
	lower	0.07c	334	ns	1.50b	107	ns	0.05b	292	0.25*	0.10a	354	ns	1.65a	100	ns
6	upper	2.21a	117	0.68**	0.25a	218	0.41*	0a	-	ns	0a	-	-	2.47a	104	0.47**
	middle	0.63b	229	ns	1.51b	131	ns	0.01a	543	ns	0.03a	543	ns	2.16a	108	ns
	lower	0.13c	523	ns	1.02b	89	0.54**	0.04a	377	0.62**	0.33b	219	ns	1.28b	97	ns
7	upper	1.09a	161	0.31*	0.23a	229	ns	0a	-	ns	0a	-	-	1.32a	138	ns
	middle	0.43b	182	0.32*	0.86b	132	ns	0.01a	573	ns	0.03ab	543	0.31*	1.31a	110	ns
	lower	0.11c	280	ns	0.63b	93	ns	0.03a	319	0.31*	0.25b	300	ns	0.85a	92	ns
8	upper	0.35a	221	0.67**	0.35a	215	ns	0a	-	ns	0a	-	-	0.70a	156	0.50**
	middle	0.14a	236	0.52**	0.76b	116	0.20+	0.04ab	323	0.32*	0a	-	-	0.94a	107	0.30*
	lower	0.02b	401	ns	0.41a	119	ns	0.14b	243	0.71**	0.25a	342	ns	0.65a	126	0.26+

[1]r^2 values for regression equation between whole plant data and disc punch data.

[2]Includes all nymphs except parasitized and red-eyed nymphs.

[3]means followed by letters are significantly different ($p < 0.05$) according to pair-wise t-test.

[4]**,*,+ indicate r^2 significant at $p < 0.01$, $p < 0.05$, and $p < 0.10$, respectively; ns = not significant at $p < 0.10$.

Table 6-3. Immature *B. argentifolii* on bean sampled on whole leaves from three strata – mean numbers per cm^2, coefficients of variation, and r^2 values[1]

		Eggs			Nymphs[2]			Parasitized nymphs			Red-eyed nymphs			Total		
Wk	Stratum	Mean	CV	r^2	Mean	CV	r^2	Mean	CV	r^2	Mean	CV	r^2	Mean	CV	r^2
1	first true leaves	1.82	67	0.90**[4]	0	-	-	0	-	-	0	-	-	1.82	67	0.90**
3	upper	0.65a[3]	78	0.19+	0.23a	277	ns	0a	-	-	0a	-	-	0.88a	119	ns
	middle	0.62a	70	0.56**	2.5b	60	0.52**	0.01a	403	0.45**	0.007a	381	ns	3.1b	59	0.63**
4	upper	0.65a	78	0.71**	0.1a	232	ns	0.001a	548	ns	0a	-	-	0.76a	84	0.52**
	middle	0.47ab	68	0.40*	1.12b	110	0.56**	0a	-	-	0a	-	-	1.58b	84	0.77**
	lower	0.31b	122	ns	1.98c	67	0.29*	0.07b	118	0.21*	0.01a	548	0.96**	2.36b	67	ns
5	upper	1.20a	103	ns	0.09a	283	ns	0a	-	-	0a	-	-	1.29a	98	ns
	middle	0.39b	137	0.21+	0.53b	101	0.50**	0.003a	548	ns	0a	-	-	0.92a	85	0.29*
	lower	0.02c	344	ns	0.91b	93	0.41*	0.04b	168	0.60**	0.03a	288	0.64**	1.01a	86	0.28*
6	upper	1.36a	103	0.50**	0.17a	232	0.42**	0a	-	-	0a	-	-	1.55a	85	0.42**
	middle	0.53b	182	ns	0.77b	85	ns	0.003a	547	ns	0.007a	548	ns	1.30a	95	0.33*
	lower	0.06c	283	ns	0.83b	71	0.64**	0.05b	156	0.84**	0.07b	133	0.26+	1.00a	65	0.20+
7	upper	0.95a	130	0.58**	0.18a	180	ns	0.001a	395	ns	0a	-	-	1.13a	109	0.50**
	middle	0.25b	130	0.33*	0.69b	139	0.33*	0.01a	429	ns	0.01ab	548	ns	0.95ab	117	0.30*
	lower	0.03c	297	ns	0.40ab	93	ns	0.04a	232	0.58**	0.03b	182	ns	0.51b	86	ns
8	upper	0.24a	190	0.82**	0.23a	168	ns	0a	-	-	0a	-	-	0.46a	118	0.61**
	middle	0.12ab	251	0.43**	0.68b	136	0.40*	0.03b	213	ns	0.003ab	548	ns	0.82a	142	0.38+
	lower	0.01b	207	ns	0.26a	96	0.46**	0.14b	203	0.84**	0.08b	209	0.44**	0.49a	121	0.74**

[1] r^2 values for regression equation between whole plant data and disc punch data.

[2] Includes all nymphs except parasitized and red-eyed nymphs.

[3] means followed by letters are significantly different ($p < 0.05$) according to pair-wise t-test.

[4] **,*,+ indicate r^2 significant at $p < 0.01$, $p < 0.05$, and $p < 0.10$, respectively; ns = not significant at $p < 0.10$.

Table 6-4. Parameters for the Taylor power law for eggs and nymphs from three sample units

Sample unit	ln [*a*]	*b*	r^2	n[1]
Egg				
Disc (upper stratum)	0.056	1.12	0.867**[2]	7
Leaf (upper stratum)	-0.254	1.09	0.555+	7
Whole plant	-0.586	1.42	0.628*	7
Nymph				
Disc (lower stratum)	-0.064	1.47	0.955**	7
Leaf (lower stratum)	-0.235	1.60	0.979**	7
Whole plant	-0.560	1.88	0.673*	7

[1] Each sample point represents the mean of 60 disc counts, 30 whole leaf counts, or 15 whole plant counts from 7 weeks.

[2] **, *, and + indicate significance at $p < 0.01$, 0.05, and 0.1, respectively.

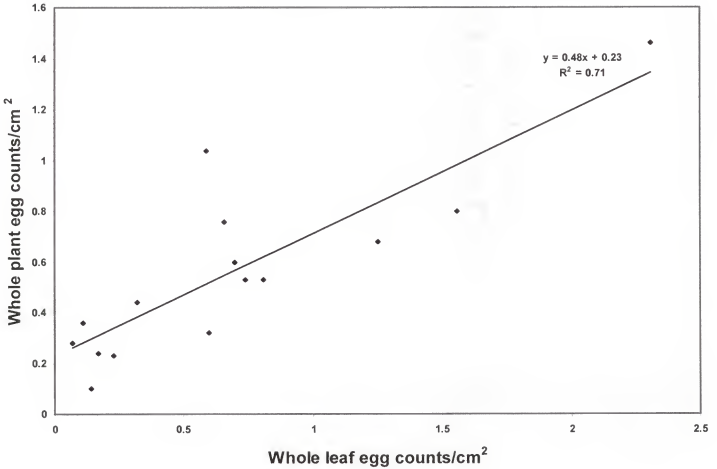

Fig. 6-1. Regression showing the relationship between whole plant egg counts/cm^2 to upper stratum whole leaf egg counts/cm^2 on 15 bean plants during week 4 of sampling.

CHAPTER 7
SUMMARY AND CONCLUSIONS

A series of field experiments carried out in north central Florida and central Guatemala failed to reduce densities of immature whiteflies (Homoptera: Aleyrodidae) through intercropping. In Florida, attempts to reduce oviposition of *Bemisia argentifolii* on common bean (*Phaseolus vulgaris* L.) by intercropping with more "attractive" crops (squash (*Cucurbita pepo* L.)and eggplant (*Solanum melongena* L.)) were not successful. Attempts to reduce oviposition on bean in Florida, and on bean and tomato (*Lycopersicon esculentum* Mill.) in Florida and Guatemala, by intercropping with poor and non-hosts such as corn (*Zea mays* L.) were also unsuccessful. Counts of adult *B. argentifolii* on yellow sticky traps from a barrier crop study indicated that whitefly adults can enter where air currents enter, and that the presence of a corn barrier only marginally reduced penetration of adults into experimental plots.

A plastic mulch painted with a reflective aluminum strip reduced whitefly egg densities on bean during the first week of sampling in 1996 and 1997 in Florida. Imidacloprid protected bean from damage by whiteflies and other sucking insects during the dry season, and reduced densities of immature whiteflies on tomato during the rainy season at the Guatemala site. However neither reflective mulch combined with a squash "trap" crop, nor imidacloprid combined with non- and poor-host intercrops, offered any additional advantage in reducing whitefly densities over these control measures alone. A spray rotation of vegetable oil and laundry detergent (1% mixed with water) did not protect a dry-season bean crop from whiteflies or other sucking insects.

Cilantro (*Coriandrum sativum* L.) and rosa de jamaica (*Hibiscus sabdariffa* L.) supported high numbers of beneficial insects at the Guatemala site. However, tomato intercropped with these crops did not have higher numbers of natural enemies than tomato grown in monoculture. Predators found on tomato were predominantly spiders.

The failure to reduce densities of immature whiteflies through intercropping is probably due to aspects of whitefly behavior discussed in the literature. *Bemisia argentifolii*, *Bemisia tabaci*, and *Trialeurodes vaporariorum* are all highly polyphagous species. They apparently do not rely on host-specific visual or olfactory cues for host-finding, responding rather to the broad range of greenish-yellow light spectra emitted by most vegetation (Coombe 1981, 1982, Vaishampayan et al. 1975a, van Lenteren and Noldus 1990). It is likely that these species must probe a crop in order to determine its suitability as a host (Hunter et al. 1996, Lei et al. 1998). It may therefore be unlikely that whitefly adults will be drawn away from one crop by the presence of another crop, even if this second crop normally elicits greater rates of feeding or oviposition than the first crop. Since the trap cropping mechanism relies largely on influencing choices made in the host-seeking stage, it may not be an effective method for managing polyphagous whiteflies.

While whiteflies are highly dispersive, they are weak fliers, relying on wind currents to take them from crop to crop until an acceptable host is found (Byrne and Bellows 1991). The presence of non-hosts may increase the movement of whitefly adults within a cropped area, but may not encourage the emigration of adults from a cropped area as has been demonstrated with more mobile herbivores in intercropping studies (Bach 1980a, 1980b, Risch 1981). Whitefly adults may simply move short distances in intercropping systems that contain non-hosts until acceptable hosts are found.

APPENDIX
SOME WHITEFLY HOSTS AT DIFFERENT ELEVATIONS IN EASTERN GUATEMALA

Location	Host	Whitefly species[1]	Population levels
Salamá Valley,	*Cajanus cajan*	*T. vaporariorum*	Moderate-high
Baja Verapaz	*Canavalia* sp.	?	Very low[2]
Elevation: 1000 m	*Mucuna deeringiana*	?	Very low[2]
	Phaseolus vulgaris[3]	*T. vaporariorum*	High
		B. tabaci	Low
	Lycopersicon esculentum	*T. vaporariorum*	High
		B. tabaci	Low
	Citrullus vulgaris	*T. vaporariorum*	Moderate
	Cucurbita pepo	*T. vaporariorum*	High
	Cucumis sativus	*T. vaporariorum*	High
	Sechium edule	*T. vaporariorum*	High
	Brassica oleracea[4]	*T. vaporariorum*	Very low
	Hibiscus sabdariffa	*B. tabaci*	Very low
Sanarate,	*Phaseolus vulgaris*	*T. vaporariorum*	High
El Progreso	*Cucumis sativus*	*T. vaporariorum*	High
Elevation: 750-850 m	*Lycopersicon esculentum*	*T. vaporariorum*	High
Rio Hato,	*Cucumis sativus*	*Bemisia argentifolii*	High
El Progreso	*Lycopersicon esculentum*	*Bemisia argentifolii*	High
Elevation: 300 m			

[1]Dr. Andrew Jensen, formerly of the USDA, Beltsville, MD, identified *T. vaporariorum* across elevations and *Bemisia* from Rio Hato. Dr. Avas Hamon of the Division of Plant Industry, Gainesville, FL, identified *Bemisia* and additional *T. vaporariorum* from the Salamá valley. *T. vaporariorum* on *C. cajan* identified by H. A. Smith

[2]Only a few eggs and early instar nymphs found on young leaves.

[3]The predominant whitefly species in the Salamá valley is *Trialeurodes vaporariorum*. Whitefly populations were highest at the end of the dry season (May), lowest early in the rainy season (June-September), and increasing at the end of the rainy season (October-November) in 1998. Observations of *B. tabaci* were low throughout the year. Based on identifications of fourth-instar nymphs carried out by H. A. Smith, *B. tabaci* on bean was estimated at 11% of the total population at the end of the dry season, 46% in the middle of the rainy season, when overall populations were at their lowest, and 0.5% on tomato at the end of the rainy season.

[4]cabbage

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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